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Institut für Heiße Chemie
Projekt Wiederaufarbeitung und Abfallbehandlung

Calculation and Compilations of Composition, Radioactivity, Thermal Power, Gamma and Neutron Release Rates of Fission Products and Actinides of Spent Power Reactor Fuels and Their Reprocessing Wastes.

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ABSTRACT

Calculations have been performed for the element and nuclide composition, radio activity, thermal decay power, gamma and neutron release rates of the isotopes present in fuel element cladding and structural parts, spent fuels, and wastes as a function of time after reactor discharge or after reprocessing, respectively. The results are compiled in diagrams and tables for the following 1000 MW_e reference reactor designs and equilibrium fuel cycles: LWR, 3,3% enriched U, 34000 MWd/t heavy metal; LWR, 4,5% enriched U, 45300 MWd/t; LWR, first and second Pu recycle and about 19% of fissile charge Pu.

Zusammenfassung

Die Element- und Nuklidzusammensetzung, Radioaktivität, Zerfallswärmeleistung, Gamma- und Neutronenemissionsraten von Hüll- und Strukturmaterial, bestrahltem Brennstoff und vom radioaktiven Abfall wurden als Funktion der Zeit nach Reaktorentladung, bzw. nach der Wiederaufarbeitung berechnet. In zahlreichen Diagrammen und Tabellen werden die Ergebnisse für folgende 1000 MW_e Referenzreaktoren und Gleichgewichts-Brennstoffzyklen zusammengefaßt: LWR mit 3,3% angereichertem U, 34000 MWd/t Schwermetall; LWR mit 4,5% angereichertem U, 45300 MWd/t; LWR mit 1. und 2. Pu-Rezyklierung, ca. 19% Anteil an spaltbarem Pu.

INTRODUCTION

The isotopic composition of the fission products and transuranium elements present in spent power reactor fuels and radioactive wastes from reprocessing of these fuels is of importance in many activities in the field of fuel reprocessing and waste management. This information as presented in this report, was prepared for the purpose of assisting in the development and design of a large fuel reprocessing plant (an activity in progress presently in the Federal Republic of Germany) as well as for waste disposal procedures.

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CALCULATIONS

Calculations have been performed for the element and nuclide composition, radioactivity, and thermal power of the isotopes present in fuel element cladding and structural parts, spent fuels, and wastes as a function of time after reactor discharge or after reprocessing, respectively. For the calculations a set of fuel cycle programs were used to obtain accurate global descriptions of the reference reactors. This information, together with the ORIGEN isotope generation and depletion code [1], was used to calculate the characterics of the spent fuels.

The calculations have been performed for the following 1000 MW_e reference reactor designs and fuel cycles.

- LWR
  (pressurized light water reactor - design SIEMENS)
  equilibrium fuel cycle,
  3.3 % enriched uranium,
  annual fuel replacement 26,0 t U/GW_ea (load factor 0.8)
  refueling fraction 1/3 of core
  burn-up 34000 MWd/t heavy metal at a specific power of 29,5 MW
  fuel element cladding and structural parts 414 kg/t HM

- LWR
  equilibrium fuel cycle,
  4.5 % enriched uranium,
  burn-up 45300 MWd/t HM

- LWR
  first and second plutonium recycle,
  ~19 % of fissile charge plutonium,
  burn-up 34000 MWd/t HM

- FBR
  (reference oxide fueled sodium cooled fast breeder reactor - design INTERATOM / Projekt Schneller Brüter)
  equilibrium fuel cycle,
  annual fuel replacement 34.4 t HM/GW_ea (load factor 0.8)
  burn-up of core 70000 MWd/t heavy metal,
  averaged burn-up of core and blanket 34000 MWd/t HM

For the LWR reactor type only the pressurized light water reactor (PWR) was considered. However, of the LWR's in operation or to be built, only approximately 50 % will be PWR's. At present the boiling water reactor (BWR) does not achieve as high a burn-up as the PWR. In the future the burn-up achieved in BWR's may reach that of PWR's. Therefore by assuming only PWR's in the calculations the results presented are on the conservative side.

It was assumed that in more than 90 % of all LWR's Zircaloy-4 will be used as fuel element cladding. A portion of the fuel element structural material consists of stainless steel and Inconel. The composition (weight percent) of the alloys used for the calculations were

Zircaloy-4	Stainless Steel 4550	Inconel
Zr 98.29 %	Fe 68.9 %	Ni 76.0 %
Sn 1.5	Cr ≤18.0	Cr 15.5
Fe 0.12	Ni ≤10.0	Fe 7.0
Cr 0.09	Mn ≤ 2.0	Mn 0.35
	Si ≤ 1.0	Si 0.20
	C ≤ 0.1	C 0.04

RESULTS

The results of the computations are in good agreement with similar calculations reported in the literature [2,3]. Larger differences seem to exist with plutonium recycle fuel, however, the reason for these differences turn out to be primarily in the amount of plutonium recycled to the reactor. The results are presented in diagrams in the first part of the paper and compiled in tables in the second part.

Tables 1 and 2 summarize the composition, in grams/t of heavy metal and gramatoms/t HM, of different irradiated fuel types 150 days after reactor discharge. The elements have been classified according to the groups of the periodic table. In addition, the nuclide concentrations of the actinide group (in grams/t HM) are listed in Table 3.

Fig. 1 shows the quantities of fission product elements (in grams/t HM) and the weight changes due to decay within ten years after reactor discharge. (The corresponding values are listed in Table 4). The fraction of stable isotopes of the fission product elements are indicated (in weight-percent) in parentheses for 30 days and 10 years cooling time.

The transuranium element and nuclide concentrations after reactor discharge are shown in Fig. 2 for an LWR with an equilibrium uranium fuel cycle and in Fig. 3 with the first plutonium recycle.

In the next group of diagrams (Fig. 4 to 7) the total radioactivity (in curies/t HM) of the fuel elements, the nuclide radioactivity of fission products and actinides, as well as the thermal decay power (in watts/t HM) of LWR fuels are plotted for decay times up to 10 years.

Tables 5 to 11 show the corresponding values of the nuclide activities and thermal decay power for cooling times from 30 days to 10 years.

All half-lives of the radioactive nuclides listed in the tables have been taken from the ORIGEN computer program.

For the plutonium recycling it was assumed that the quantity recycled in the LWR was the same as the quantity produced in the same reactor. The isotopic composition of the recycled Pu charged to this reactor was taken to be that calculated for the LWR fueled with 3.3 % enriched uranium at 150 days cooling plus one year before fuel fabrication. Because of the introduction of the plutonium fueled commercial fast breeder reactors probably in the early 1990's a maximum of only two plutonium recycles in LWR's was assumed. In addition, the plutonium isotopic composition, and, therefore, the production of the transplutonium isotopes, does not change significantly after the second recycle.

The following figures and tables show the element and nuclide concentrations, nuclide radioactivity of fission products and actinides and the thermal decay power, respectively, of the radioactive wastes generated at reprocessing of different fuels 150 days after reactor discharge. One percent of the uranium and one percent of the plutonium have been assumed to be lost with the high level waste (HAW) stream, while the non-gaseous fission products, neptunium, americium, curium, the transcurium elements, and the decay products are quantitatively contained in the HAW. The higher quantities of americium and curium in the high level waste from processed plutonium recycle fuel will be compensated very probably by the lower content in the HAW from processed initial-core or lower burn-up fuels.

Fig. 8 to 11 show the short term waste decay up to 10 years after reprocessing, Fig. 12 to 14 the long-term waste decay.

More than 2/3 of the non-gaseous fission product elements as well as uranium and neptunium listed in Table 1, do not change weight more than ± 10 percent within the first few hundred years. The weight changes of the remaining fission product and trans-uranium elements, which are caused either by decay of their own isotopes or production from the decay of isotopes of a neighbor element, are listed in Table 12.

Tables 13 to 19 present the nuclide radioactivity and the nuclide thermal decay power of the radioactive wastes generated at reprocessing of different LWR fuels (uranium cycle with 34000 MWd/t HM and 45000 MWd/t HM burn-up and plutonium recycle) 150 days after reactor discharge.

Tables 20 and 21 show the nuclide activity and thermal power of the activated Zircaloy fuel element cladding (hulls) and structural materials per ton of heavy metal initially charged to the reactor.

Fig. 15 and 16 present the photon release rates and the spontaneous fission and (α,n) neutron source of cladding and structural materials, fission products, and actinides of spent LWR fuels and waste. Table 22 summarizes the photon release rates of LWR fuel for different energy groups, table 23 the neutron source of spent fuel and waste. The isotopes ^{242}Cm and ^{244}Cm have a considerable spontaneous fission activity. Consequently, these isotopes are expected to present a shielding problem in transportation of irradiated fuels and in shipping and disposal of wastes, due to the spontaneous fission neutron source. The results of the calculations indicate a high increase in the amount of curium isotopes produced in plutonium recycle fuel. At decay times of 3 to 5 years the neutron source decreases only 18 to 24 percent.

Table 24, finally, summarizes quantities (in kg/1500 jato), radioactivity and thermal power of the waste produced by a reprocessing plant having 1500 tons annual throughput.

REFERENCES

[1] M.J. BELL, "ORIGEN-The ORNL Isotope Generation and Depletion Code", Report ORNL-4628 (May 1973)

[2] ORNL Staff, "Siting of Fuel Reprocessing Plants and Waste Management Facilities", Report ORNL-4451 (July 1970)

[3] M.J. BELL, "Heavy Element Composition of Spent Power Reactor Fuels", Report ORNL-TM-2897 (May 1970)

ABBREVIATIONS

LWR	- light water moderated reactor
PWR	- pressurized water reactor
BWR	- boiling water reactor
FBR	- fast breeder reactor (here sodium cooled oxide fast breeder reactor)
T; t	- metric ton
HM	- heavy metals
MW	- mega watts thermal = 10^6 watts
GW	- giga watts thermal = 1000 mega watts
FP	- fission products
ACT	- actinide elements
TU	- transuranium elements
HAW	- high active waste
n SF	- neutrons by spontaneous fission
n (α,n)	- neutrons by alpha-n reaction
S	- seconds
M	- minutes
H	- hours
Y; a	- years
3.0E+07	- stands for $3.0 \cdot 10^7$
JATO	- plant through-put, tons per year

TABLE 1 ELEMENT CONCENTRATIONS IN SPENT FUELS
150 DAYS AFTER REACTOR DISCHARGE
(GRAMS/T HM)

ELEMENT	LWR		LWR PU-RECYCLING		FBR
	34 GWD/T	45 GWD/T	34 GWD/T		CORE+BLANKET 34 GWD/T
			1.RECYCLE	2.RECYCLE	SBR - Pu !
H-3	0.074	0.095	0.080	0.080	0.099
HE	0.37	0.54	1.69	2.13	0.32
KR	382	526	345	344	292
XE	5590	7450	5610	5600	4230
RB	341	472	305	303	252
CS	2800	3690	2840	2850	3840
SR	914	1260	818	815	558
BA	1440	1950	1450	1450	1410
Y	480	663	426	424	312
LA	1300	1740	1290	1280	1180
CE	2790	3720	2730	2720	2630
PR	1230	1650	1190	1190	990
ND	3990	5400	3890	3880	3520
PM	104	116	106	107	336
SM	834	1100	848	848	987
EU	191	258	205	205	143
GD	113	172	128	127	106
TB	1.9	2.2	2.4	2.4	8.6
DY	1.1	1.4	1.5	1.5	3.7
U	954000	942000	952000	952000	867000
NP	500	769	376	368	271
PU	9080	9510	10600	11000	101000
AM	153	208	544	774	259
CM	42.9	72.5	317	524	4.8
ZR	3760	5110	3540	3530	3060
NB	12.9	15.2	12.8	12.7	21.0
MO	3540	4730	3520	3520	3350
TC	863	1140	865	866	913
RU	2340	3050	2490	2490	3100
RH	391	460	424	427	923
PD	1350	1730	1660	1660	2170
AG	62.3	70.9	78.2	79.0	214
CD	88.4	115	117	117	129
IN	1.2	1.3	1.4	1.4	13.7
SN	53.5	67.1	62.3	62.5	138
SB	17.7	21.9	20.4	20.4	52.0
SE	53.3	72.4	50.8	50.7	59.3
TE	582	763	619	619	580
BR	15.7	21.0	15.4	15.4	22.4
J	277	357	300	301	293

TABLE 2 ELEMENT CONCENTRATIONS IN SPENT FUELS
150 DAYS AFTER REACTOR DISCHARGE
(GRAM ATOMS/T HM)

ELEMENT	LWR		LWR PU-RECYCLING		FER CORE+BLANKET
	34 GWD/T	45 GWD/T	34 GWD/T		34 GWD/T
			1.RECYCLE	2.RECYCLE	
H-3	0.025	0.032	0.027	0.027	0.033
HE	0.093	0.134	0.422	0.532	0.081
KR	4.50	6.19	4.06	4.04	3.44
XE	41.6	55.5	41.8	41.7	31.6
RB	3.95	5.47	3.53	3.51	2.92
CS	20.7	27.3	21.0	21.1	28.4
SR	10.2	14.1	9.17	9.13	6.26
BA	10.4	14.2	10.5	10.5	10.2
Y	5.39	7.45	4.78	4.76	3.5
LA	9.38	12.6	9.25	9.24	8.50
CE	19.7	26.3	19.3	19.3	18.6
PR	8.71	11.7	8.46	8.45	7.02
ND	27.5	37.3	26.8	26.8	24.3
PM	0.707	0.786	0.721	0.728	2.29
SM	5.57	7.36	5.66	5.66	6.58
EU	1.25	1.68	1.34	1.34	0.932
GD	0.726	1.10	0.819	0.810	0.677
TB	0.012	0.014	0.015	0.015	0.054
DY	0.007	0.009	0.009	0.009	0.023
U	4010.	3960.	4000.	4000.	3640.
NP	2.11	3.24	1.59	1.55	1.14
PU	37.9	39.7	44.3	45.9	421.
AM	0.632	0.856	2.24	3.19	1.07
CM	0.176	0.297	1.30	2.15	0.020
ZR	40.3	54.8	37.9	37.8	32.7
NB	0.136	0.16	0.134	0.134	0.221
MO	36.2	48.5	36.1	36.0	34.3
TC	8.72	11.5	8.74	8.74	9.22
RU	22.9	29.9	24.4	24.4	30.2
RH	3.79	4.47	4.12	4.15	8.96
PD	12.7	16.3	15.6	15.7	20.4
AG	0.572	0.650	0.717	0.725	1.96
CD	0.792	1.03	1.05	1.05	1.15
IN	0.011	0.012	0.012	0.012	0.119
SN	0.438	0.554	0.509	0.511	1.13
SB	0.143	0.178	0.165	0.166	0.422
SE	0.659	0.894	0.628	0.626	0.735
TE	4.50	5.89	4.78	4.79	4.48
BR	0.194	0.259	0.190	0.190	0.276
J	2.15	2.77	2.34	2.34	2.28

TABLE 3 ACTINIDE NUCLIDE CONCENTRATIONS IN SPENT FUELS
150 DAYS AFTER REACTOR DISCHARGE
(GRAMS/T HM)

NUCLIDE	HALF-LIFE		LWR		LWR PU-RECYCLING		FBR
			34 GWD/T	45 GWD/T	34 GWD/T		CORE+BLANKET 34 GWD/T
					1.RECYCLE	2.RECYCLE	
U-234	247000	Y	119	389	105	108	0.9
U-235	7.10E+8	Y	7560	8210	6890	7070	2330
U-236	2.39E+7	Y	4580	6450	3600	3580	330
U-238	4.51E+9	Y	942000	927000	941000	942000	864000
NP-237	2.13E+6	Y	500	769	376	368	271
PU-238	88.9	Y	180	304	237	260	30
PU-239	24400	Y	5270	5260	5360	5360	75800
PU-240	6760	Y	2200	2310	2610	2650	22100
PU-241	14.6	Y	1050	1160	1440	1490	2210
PU-242	380000	Y	380	488	966	1230	627
AM-241	433	Y	47.2	51.5	79.9	85.5	220
AM-242M	151	Y	1.0	1.1	2.2	2.4	2.5
AM-243	7650	Y	105	155	462	686	36.8
CM-242	163	D	5.8	4.7	14.7	16.3	2.7
CM-243	32.0	Y	0.1	0.1	0.3	0.4	0.2
CM-244	18.1	Y	34.4	60.0	273	456	1.9
CM-245	8260	Y	2.3	4.4	24.2	42.0	0.04
CM-246	4710	Y	0.3	0.6	4.8	8.8	
TOTAL TU			9776	10568	11850	12655	101302

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* ELEMENT CONCENTRATIONS
* LWR  EQ. URANIUM FUEL CYCLE
* BURN-UP 34000 MWD/T HM
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TABLE 4 ELEMENT CONCENTRATIONS IN SPENT LWR FUEL
(GRAMS/T HM - FUEL DECAY TIMES AFTER REACTOR DISCHARGE)

ELEMENT	30 DAYS	90 DAYS	150 DAYS	1 YEAR	3 YEARS	10 YEARS
H-3	0.075	0.074	0.074	0.071	0.064	0.043
KR	383	383	382	381	378	369
XE	5580	5590	5590	5590	5590	5590
RB	341	341	341	342	346	355
CS	2830	2810	2800	2750	2630	2380
SR	932	921	914	903	877	794
BA	1410	1420	1440	1490	1610	1850
Y	486	482	480	477	477	477
LA	1300	1300	1300	1300	1300	1300
CE	2890	2830	2790	2690	2570	2550
PR	1210	1220	1230	1230	1230	1230
ND	3910	3950	3990	4090	4200	4230
PM	113	109	104	88.8	52.3	8.2
SM	824	829	834	849	885	926
EU	194	192	191	189	184	172
GD	111	113	113	116	122	136
TB	1.9	1.9	1.9	1.9	1.9	1.9
DY	1.1	1.1	1.1	1.2	1.2	1.2
U	954000	954000	954000	954000	954000	954000
NP	500	500	500	500	501	504
PU	9090	9090	9080	9050	8960	8700
AM	137	145	153	182	274	532
CM	47.2	44.8	42.9	38.7	33.9	26.5
ZR	3770	3760	3760	3760	3790	3870
NB	32.0	21.7	12.9	1.5	0.002	
MO	3480	3520	3540	3560	3560	3560
TC	863	863	863	863	863	863
RU	2400	2360	2340	2300	2240	2220
RH	371	386	391	394	394	394
PD	1320	1340	1350	1390	1460	1480
AG	62.6	62.4	62.3	62.1	61.8	61.8
CD	88.2	88.4	88.4	88.7	88.9	89.0
IN	1.2	1.2	1.2	1.2	1.3	1.3
SN	53.9	53.7	53.5	53.2	53.1	53.1
SB	17.9	17.8	17.7	16.9	14.4	11.1
SE	53.3	53.3	53.3	53.3	53.3	53.3
TE	583	582	582	583	585	589
BR	15.7	15.7	15.7	15.7	15.7	15.7
J	276	277	277	278	278	278

REFERENCE LWR - EQUILIBRIUM FUEL CYCLE
3.3 % ENRICHED URANIUM
BURN-UP 34000 MWD/T HM, SPECIFIC POWER 29.5 MW/T, FLUX 2.90E+13 N/SEC*CM**2

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* FUEL RADIOACTIVITY
* LWR  EQ. URANIUM FUEL CYCLE
* BURN-UP 34000 MWD/T HM
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TABLE 5 NUCLIDE RADIOACTIVITY OF SPENT LWR FUEL
(CURIES/T HM - FUEL DECAY TIMES AFTER REACTOR DISCHARGE)

NUCLIDE	HALF-LIFE		30 DAYS	90 DAYS	150 DAYS	1 YEAR	3 YEARS	10 YEARS
H-3	12.3	Y	727	720	713	690	616	415
KR-85	10.8	Y	11400	11300	11200	10800	9490	6060
XE-131M	12.0	D	2600	104	3.2			
XE-133	5.3	D	37300	14				
RB-86	18.7	D	164	18	1.9			
CS-134	2.1	Y	250000	237000	224000	184000	93300	8750
CS-135	3.00E+6	Y	0.3	0.3	0.3	0.3	0.3	0.3
CS-136	13.0	D	12800	522	21			
CS-137	30.0	Y	111000	110000	110000	108000	103000	87900
BA-137M	2.6	M	103000	103000	103000	101000	96600	82200
SR-89	52.1	D	464000	209000	93800	5340	0.3	
SR-90	28.1	Y	78900	78600	78300	77200	73500	61800
BA-140	12.8	D	277000	10800	417			
Y-90	64.0	H	78900	78700	78300	77200	73500	61800
Y-91	59.0	D	642000	316000	156000	12400	2.2	
LA-140	40.2	H	319000	12400	480			
CE-141	32.3	D	716000	198000	55000	553		
CE-144	284	D	1020000	880000	760000	450000	75500	150
PR-144	17.3	M	1020000	880000	760000	450000	75500	150
PR-143	13.7	D	287000	13800	663			
ND-147	11.1	D	87900	2070	49			
PM-147	2.6	Y	104000	101000	96400	82500	48600	7630
PM-148M	42.0	D	23200	8610	3200	92		
PM-148	5.4	D	5910	694	257	7.4		
SM-151	87.2	Y	1280	1270	1270	1270	1250	1180
EU-152	12.0	Y	12.8	12.7	12.6	12.2	10.8	7.2
EU-154	16.0	Y	7370	7310	7260	7080	6490	4790
EU-155	1.8	Y	7610	7150	6710	5360	2490	171
EU-156	15.0	D	61000	3810	238			
GD-153	242	D	35	30	25	14	1.7	
TB-160	72.3	D	1000	562	316	40		
ZR-93	1.50E+6	Y	1.9	1.9	1.9	1.9	1.9	1.9
NB-93M	13.6	Y	0.2	0.2	0.2	0.2	0.4	0.9
ZR-95	65.2	D	973000	513000	271000	27300	11	
NB-95M	90.0	H	20700	10900	5750	580	0.2	
NB-95	35.0	D	1250000	852000	508000	58100	24	
TC-99	210000	Y	15	15	15	15	15	15
RU-103	39.5	D	710000	249000	86900	2020		
RH-103M	57	M	711000	249000	86900	2020		
RU-106	1.0	Y	524000	468000	418000	278000	70000	560
RH-106	30.0	S	524000	468000	418000	278000	70000	560
PD-107	7.00E+6	Y	0.1	0.1	0.1	0.1	0.1	0.1
AG-110M	253	D	3570	3030	2570	1420	192	0.1
AG-110	24.4	S	464	393	334	185	25	
AG-111	7.5	D	2470	9.6				
CD-113M	14.0	Y	11.3	11.2	11.0	10.8	9.8	6.9
CD-115M	43	D	338	128	49	1.5		
SN-119M	250	D	15	13	11	6.0	0.8	
SN-123	125	D	7490	5370	3850	1170	20	
SN-125	9.4	D	1450	17	0.2			
SN-126	100000	Y	0.6	0.6	0.6	0.6	0.6	0.6
SB-126M	19	M	0.6	0.6	0.6	0.6	0.6	0.6
SB-126	12.4	D	11.5	1.0	0.6	0.6	0.6	0.6
SB-124	60	D	299	149	75	6.2		
SB-125	2.7	Y	8890	8530	8180	7030	4210	698
SE-79	65000	Y	0.4	0.4	0.4	0.4	0.4	0.4
TE-125M	58.1	D	3300	3350	3300	2910	1740	289
TE-127M	109	D	13100	8960	6120	1560	15	
TE-127	9.4	H	13300	8850	6050	1540	15	
TE-129M	34	D	30700	9050	2660	33		
TE-129	69	M	19700	5800	1710	21		
J-129	1.70E+7	Y	0.1	0.1	0.1	0.1	0.1	0.1
J-131	8.0	D	65600	375	2			
TH-234	24.1	D	0.3	0.3	0.3	0.3	0.3	0.3
PA-233	27.4	D	0.3	0.4	0.4	0.4	0.4	0.4
PA-234M	1.8	M	0.3	0.3	0.3	0.3	0.3	0.3
U-234	247000	Y	0.7	0.7	0.7	0.7	0.8	0.8
U-236	2.39E+7	Y	0.3	0.3	0.3	0.3	0.3	0.3
U-237	6.7	D	39500	86	2.7	2.5	2.3	1.6
U-238	4.51E+9	Y	0.3	0.3	0.3	0.3	0.3	0.3
NP-237	2.13E+6	Y	0.4	0.4	0.4	0.4	0.4	0.4
NP-239	2.4	D	2660	20	20	20	20	20
PU-236	2.8	Y	0.4	0.4	0.3	0.3	0.2	
PU-238	88.9	Y	2970	3010	3030	3070	3060	2900
PU-239	24400	Y	323	323	323	323	323	323
PU-240	6760	Y	485	485	485	485	486	487
PU-241	14.6	Y	108000	107000	106000	103000	94000	67400
PU-242	380000	Y	1.5	1.5	1.5	1.5	1.5	1.5
AM-241	433	Y	105	134	162	260	575	1460
AM-242M	151	Y	9.8	9.8	9.8	9.8	9.7	9.4
AM-242	26	H	9.8	9.8	9.8	9.8	9.7	9.4
AM-243	7650	Y	20.2	20.2	20.2	20.2	20.2	20.2
CM-242	163	D	32000	24800	19200	7710	352	7.7
CM-243	32.0	Y	4.1	4.1	4.1	4.1	3.9	3.3
CM-244	18.1	Y	2820	2810	2790	2730	2520	1930
CM-245	8260	Y	0.4	0.4	0.4	0.4	0.4	0.4
SUM FP			1.06E+7	6.14E+6	4.38E+6	2.24E+6	806000	325000
SUM ACT			1.89E+5	1.39E+5	1.32E+5	1.18E+5	101000	74600
TOTALS			1.08E+7	6.28E+6	4.51E+6	2.36E+6	907000	400000

REFERENCE LWR - EQUILIBRIUM FUEL CYCLE
3.3 % ENRICHED URANIUM
BURN-UP 34000 MWD/T HM, SPECIFIC POWER 29.5 MW/T, FLUX 2.90E+13 N/SEC*CM**2

* FUEL THERMAL DECAY POWER
* LWR EQ. URANIUM FUEL CYCLE
* BURN-UP 34000 MWD/T HM
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TABLE 6 NUCLIDE THERMAL POWER OF SPENT LWR FUEL
(WATTS/T HM - FUEL DECAY TIMES AFTER REACTOR DISCHARGE)

NUCLIDE	HALF-LIFE	30 DAYS	90 DAYS	150 DAYS	1 YEAR	3 YEARS	10 YEARS
KR-85	10.8 Y	18.6	18.4	18.2	17.5	15.4	9.84
CS-134	2.1 Y	2650	2510	2370	1940	989	92.7
CS-136	13.0 D	176	7.2	0.3			
CS-137	30.0 Y	181	180	179	177	169	144
BA-137M	2.6 M	406	405	403	398	380	323
SR-89	52.1 D	1670	751	337	19	0.001	
SR-90	28.1 Y	103	103	103	101	96	81
BA-140	12.8 D	925	36	1.4			
Y-90	64.0 H	465	463	461	454	432	364
Y-91	59.0 D	2440	1200	594	47	0.009	
LA-140	40.2 H	563	218	8.5			
CE-141	32.3 D	1410	390	108	1.1		
CE-144	284 D	833	720	622	368	62	0.12
PR-144	17.3 M	7890	6820	5890	3480	585	1.2
PR-143	13.7 D	624	30	1.5			
ND-147	11.1 D	285	6.7	0.16			
PM-147	2.6 Y	53.7	51.9	49.7	42.5	25.1	3.9
PM-148M	42.0 D	287	107	40	1.1		
PM-148	5.4 D	47.9	5.6	2.1	0.06		
SM-151	87.2 Y	2.2	2.2	2.2	2.2	2.2	2.1
EU-154	16.0 Y	60.5	60.0	59.6	58.1	53.3	39.4
EU-155	1.8 Y	6.4	6.0	5.7	4.5	2.1	0.14
EU-156	15.0 D	606	37.9	2.4			
TB-160	72.3 D	8.5	4.8	2.7	0.34		
ZR-95	65.2 D	5090	2690	1420	143	0.06	
NB-95M	90.0 H	29	15	8	0.8		
NB-95	35.0 D	6040	4100	2440	280	0.12	
RU-103	39.5 D	2340	819	287	6.7		
RH-103M	57 M	337	118	41	0.96		
RU-106	1.0 Y	31.1	27.7	24.8	16.5	4.2	0.033
RH-106	30.0 S	5510	4920	4390	2930	735	5.9
AG-110M	253 D	60.2	51.1	43.4	24.1	3.3	0.003
AG-110	24.4 S	3.4	2.9	2.4	1.3	0.18	
SN-123	125 D	26.5	19.0	13.6	4.1	0.07	
SB-124	60 D	4.1	2.1	1.0	0.09		
SB-125	9.4 D	36.0	34.6	33.2	28.5	17.1	2.8
TE-125M	58.1 D	5.7	5.7	5.7	5.0	3.0	0.5
TE-127M	109 D	7.2	5.0	3.4	0.9	0.008	
TE-127	9.4 H	21.4	14.3	9.8	2.5	0.02	
TE-129M	39 D	61.0	18.0	5.3	0.07		
TE-129	69 M	71.6	21.1	6.2	0.08		
J-131	8.0 D	229	1.3	0.007			
PU-238	88.9 Y	98.5	99.6	100	102	101	96.2
PU-239	24400 Y	10.1	10.1	10.1	10.1	10.1	10.1
PU-240	6760 Y	15.1	15.1	15.1	15.1	15.1	15.2
PU-241	14.6 Y	4.5	4.5	4.4	4.3	3.9	2.8
AM-241	433 Y	3.5	4.5	5.4	8.7	19.2	48.7
AM-243	7650 Y	0.7	0.7	0.7	0.7	0.7	0.7
CM-242	163 D	1180	914	709	284	13	0.28
CM-244	18.1 Y	98.8	98.2	97.5	95.4	88.3	67.6
SUM FP		46800	27000	20000	10600	3570	1070
SUM ACT		1440	1150	943	521	252	242
TOTALS		48240	28150	20940	11120	3820	1310

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REFERENCE LWR - EQUILIBRIUM FUEL CYCLE
3.3 % ENRICHED URANIUM
BURN-UP 34000 MWD/T HM, SPECIFIC POWER 29.5 MW/T, FLUX 2.90E+13 N/SEC*CM**2

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* FUEL RADIOACTIVITY
* LWR EQ. URANIUM FUEL CYCLE
* HIGH BURN-UP 45300 MWD/T HM
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TABLE 7 NUCLIDE RADIOACTIVITY OF SPENT LWR FUEL (HIGH BURNUP)
(CURIES/T HM - FUEL DECAY TIMES AFTER REACTOR DISCHARGE)

NUCLIDE	HALF-LIFE	30 DAYS	90 DAYS	150 DAYS	1 YEAR	3 YEARS	10 YEARS
H-3	12.3 Y	933	924	916	886	791	533
KR-85	10.8 Y	15600	15400	15300	14700	12900	8250
XE-131M	12.0 D	2990	119	4			
XE-133	5.3 D	42800	16				
RB-86	18.7 D	256	28	3			
CS-134	2.1 Y	375000	355000	336000	275000	140000	13100
CS-135	3.00E+6 Y	0.4	0.4	0.4	0.4	0.4	0.4
CS-136	13.0 D	17500	713	29			
CS-137	30.0 Y	146000	146000	145000	143000	137000	116000
BA-137M	2.6 M	137000	136000	136000	134000	128000	109000
SR-89	52.1 D	550000	247000	111000	6320	0.4	
SR-90	28.1 Y	109000	108000	108000	106000	101000	85100
BA-140	12.8 D	318000	12300	479			
Y-90	64.0 H	109000	108000	108000	106000	101000	85100
Y-91	59.0 D	761000	375000	185000	14700	3	
LA-140	40.2 H	366000	14200	551			
CE-141	32.3 D	830000	230000	63700	641		
CE-144	284 D	1250000	1080000	932000	551000	92600	184
PR-144	17.3 M	1250000	1080000	932000	551000	92600	184
PR-143	13.7 D	331000	15900	764			
ND-147	11.1 D	103000	2430	57			
PM-147	2.6 Y	116000	112000	107000	91700	54000	8480
PM-148M	42.0 D	25800	9590	3560	102		
PM-148	5.4 D	6870	772	286	8		
SM-151	87.2 Y	1560	1560	1550	1550	1520	1440
EU-152	12.0 Y	14	14	14	14	12	8.1
EU-154	16.0 Y	10600	10500	10400	10100	9300	6870
EU-155	1.8 Y	11100	10400	9810	7830	3640	249
EU-156	15.0 D	95300	5960	372			
GD-153	242 D	57	48	41	22	3	
TB-160	72.3 D	1330	748	420	53		
ZR-93	1.50E+6 Y	2.6	2.6	2.6	2.6	2.6	2.6
NB-93M	13.6 Y	0.2	0.3	0.3	0.4	0.6	1.2
ZR-95	65.2 D	1140000	602000	317000	32100	13	
NB-95M	90.0 H	24200	12800	6740	680	0.3	
NB-95	35.0 D	1480000	1000000	596000	68200	29	
TC-99	210000 Y	19	19	19	19	19	19
RU-103	39.5 D	817000	286000	100000	2320		
RH-103M	57 M	818000	286000	100000	2320		
RU-106	1.0 Y	611000	546000	487000	325000	81600	653
RH-106	30.0 S	611000	546000	487000	325000	81600	653
PD-107	7.00E+6 Y	0.1	0.1	0.1	0.1	0.1	0.1
AG-110M	253 D	4650	3940	3340	1860	250	0.2
AG-110	24.4 S	604	512	435	241	33	0.03
AG-111	7.5 D	2790	11				
CD-113M	14.0 Y	16	16	16	16	14	10
CD-115M	43 D	394	150	57	1.8		
SN-119M	250 D	18	15	13	7	0.9	
SN-123	125 D	8690	6230	4470	1360	24	
SN-125	9.4 D	1620	19	0.2			
SN-126	100000 Y	0.7	0.7	0.7	0.7	0.7	0.7
SB-126M	19 M	0.7	0.7	0.7	0.7	0.7	0.7
SB-126	12.4 D	15	1.2	0.7	0.7	0.7	0.7
SB-124	60 D	407	204	102	8.5		
SB-125	2.7 Y	10800	10400	9950	8560	5120	849
SE-79	65000 Y	0.6	0.6	0.6	0.6	0.6	0.6
TE-125M	58.1 D	4040	4080	4020	3540	2120	352
TE-127M	109 D	15200	10400	7100	1810	17	
TE-127	9.4 H	15400	10300	7020	1790	17	
TE-129M	34 D	35300	10400	3060	38		
TE-129	69 M	22600	6660	1960	25		
J-129	1.70E+7 Y	0.05	0.05	0.05	0.05	0.05	0.05
J-131	8.0 D	75100	428	2.4			
TH-234	24.1 D	0.3	0.3	0.3	0.3	0.3	0.3
U-234	247000 Y	0.02	0.02	0.02	0.03	0.06	0.2
U-236	2.39E+7 Y	0.4	0.4	0.4	0.4	0.4	0.4
U-237	6.7 D	60300	130	3	3	0.3	0.2
U-238	4.51E+9 Y	0.3	0.3	0.3	0.3	0.3	0.3
NP-237	2.13E+6 Y	0.5	0.5	0.5	0.5	0.5	0.5
NP-239	2.4 H	2920	298	30	30	30	30
PU-236	2.8 Y	0.7	0.6	0.6	0.5	0.1	0.06
PU-238	88.9 Y	5060	5010	5130	5180	5150	4880
PU-239	24400 Y	322	322	322	322	322	322
PU-240	6760 Y	508	508	509	509	510	512
PU-241	14.6 Y	120000	119000	118000	115000	104000	74700
PU-242	380000 Y	1.9	1.9	1.9	1.9	1.9	1.9
AM-241	433 Y	114	145	176	286	634	1610
AM-242M	151 Y	11	11	11	11	11	10
AM-242	16 H	11	11	11	11	11	10
AM-243	7650 Y	30	30	30	30	30	30
CM-242	163 D	40800	31600	24500	9830	447	8.5
CM-243	32.0 Y	5.9	5.9	5.9	5.8	5.6	4.8
CM-244	18.1 Y	4920	4890	4860	4750	4400	3360
CM-245	8260 Y	0.8	0.8	0.8	0.8	0.8	0.8
CM-246	4710 Y	0.2	0.2	0.2	0.2	0.2	0.2
SUM FP		1.27E+7	7.42E+6	5.34E+6	2.79E+6	1.05E+6	4.37E+5
SUM ACT		2.35E+5	1.62E+5	1.53E+5	1.35E+5	1.16E+5	8.55E+4
TOTALS		1.29E+7	7.58E+6	5.49E+6	2.92E+6	1.17E+6	5.23E+5

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REFERENCE LWR - EQUILIBRIUM FUEL CYCLE
4.5 % ENRICHED URANIUM
BURN-UP 45300 MWD/T HM, SPECIFIC POWER 35.4 MW/T, FLUX 2.99E+13 N/SEC*CM**2

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* FUEL  THERMAL DECAY POWER
* LWR  EQ. URANIUM FUEL CYCLE
* HIGH BURN-UP 45300 MWD/T HM
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TABLE 8 NUCLIDE THERMAL POWER OF SPENT LWR FUEL
(WATTS/T HM - FUEL DECAY TIMES AFTER REACTOR DISCHARGE)

NUCLIDE	HALF-LIFE	30 DAYS	90 DAYS	150 DAYS	1 YEAR	3 YEARS	10 YEARS
KR-85	10.8 Y	25	25	25	24	21	13
CS-134	2.1 Y	3970	3760	3560	2910	1480	139
CS-136	13.0 D	240	9.8	0.4			
CS-137	30.0 Y	240	239	238	235	224	190
BA-137M	2.6 M	538	536	534	527	503	428
SR-89	52.1 D	1980	889	400	23	0.001	
SR-90	28.1 Y	142	142	141	139	133	111
BA-140	12.8 D	1060	41	1.6			
Y-90	64.0 H	640	638	635	626	596	501
Y-91	59.0 D	2900	1430	704	56	0.01	
LA-140	40.2 H	6460	251	9.7			
CE-141	32.3 D	1630	453	125	1.3		
CE-144	284 D	1020	883	762	451	76	0.15
PR-144	17.3 M	9680	8360	7220	4270	718	1.4
PR-143	13.7 D	718	35	1.7			
ND-147	11.1 D	335	7.9	0.2			
PM-147	2.6 Y	60	58	55	47	28	4.4
PM-148M	42.0 D	320	119	44	1.3		
PM-148	5.4 D	56	6.3	2.3	0.07		
SM-151	87.2 Y	2.7	2.7	2.7	2.7	2.6	2.5
EU-154	16.0 Y	87	86	86	83	76	56
EU-155	1.8 Y	9.4	8.8	8.3	6.6	3.1	0.2
EU-156	15.0 D	948	59	3.7			
TB-160	72.3 D	11	6.4	3.6	0.5		
ZR-95	65.2 D	5970	3150	1660	168	0.07	
NB-95M	90.0 H	34	18	9.4	0.9		
NB-95	35.0 D	7130	4830	2870	328	0.14	
RU-103	39.5 D	2690	943	330	7.7		
RH-103M	57 M	388	136	48	1.1		
RU-106	1.0 Y	36	32	29	19	4.8	0.04
RH-106	30.0 S	6420	5730	5120	3410	858	6.9
AG-110M	253 D	79	67	57	31	4.2	
AG-110	24.4 S	4.4	3.7	3.2	1.8	0.2	
SN-123	125 D	31	22	16	4.8	0.1	
SB-124	60 D	5.6	2.8	1.4	0.1		
SB-125	2.7 Y	44	42	40	35	21	3.4
TE-125M	58.1 D	6.9	7.0	6.9	6.1	3.7	0.6
TE-127M	109 D	8.4	5.7	3.9	1.0	0.01	
TE-127	9.4 H	25	17	11	2.7	0.03	
TE-129M	34 D	70	21	6.1	0.08		
TE-129	69 M	82	24	7.1	0.09		
J-131	8.0 D	262	1.5	0.01			
PU-238	88.9 Y	168	169	170	172	171	162
PU-239	24000 Y	10	10	10	10	10	10
PU-240	6760 Y	15.8	15.8	15.8	15.8	15.9	16.0
PU-241	14.6 Y	5.0	4.9	4.9	4.8	4.3	3.1
AM-241	433 Y	3.8	4.9	5.9	9.5	21.2	53.9
AM-243	7650 Y	1.1	1.1	1.1	1.1	1.1	1.1
CM-242	163 D	1500	1170	903	362	17	0.3
CM-244	18.1 Y	172	171	170	166	154	118
SUM FP		56500	33100	24800	13400	4750	1460
SUM ACT		1920	1540	1280	742	394	364
TOTALS		58400	34700	26100	14200	5150	1830

REFERENCE LWR - EQUILIBRIUM FUEL CYCLE
4.5 % ENRICHED URANIUM
BURN-UP 45300 MWD/T HM, SPECIFIC POWER 35.4 MW/T, FLUX 2.99E+13 N/SEC*CM**2

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                                        * FUEL RADIOACTIVITY
                                        * LWR  FIRST PU-RECYCLE
                                        * BURN-UP 34000 MWD/T HM
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TABLE 9 NUCLIDE RADIOACTIVITY OF SPENT LWR FUEL (FIRST PU-RECYCLE)
(CURIES/T HM - FUEL DECAY TIMES AFTER REACTOR DISCHARGE)

NUCLIDE	HALF-LIFE		30 DAYS	90 DAYS	150 DAYS	1 YEAR	3 YEARS	10 YEARS
SUM FP			1.06E+7	6.16E+6	4.41E+6	2.27E+6	806000	313000
(INDIVIDUAL NUCLIDES SEE TABLE 5)								
TH-234	24.1	D	0.3	0.3	0.3	0.3	0.3	0.3
PA-233	27.4	D	0.3	0.3	0.3	0.3	0.3	0.3
PA-234M	1.8	M	0.3	0.3	0.3	0.3	0.3	0.3
U-234	247000	Y	0.6	0.6	0.6	0.7	0.7	0.8
U-236	2.39E+7	Y	0.2	0.2	0.2	0.2	0.2	0.2
U-237	6.7	D	30700	68	3.7	3.4	3.1	2.2
U-238	4.51E+9	Y	0.3	0.3	0.3	0.3	0.3	0.3
NP-237	2.13E+6	Y	0.3	0.3	0.3	0.3	0.3	0.3
NP-239	2.4	D	2650	89	89	89	89	89
PU-236	2.8	Y	0.4	0.4	0.3	0.3	0.2	0.03
PU-238	88.9	Y	3850	3940	4010	4130	4160	3950
PU-239	24400	Y	328	328	328	328	328	328
PU-240	6760	Y	574	574	575	576	580	592
PU-241	14.6	Y	149000	148000	147000	143000	130000	93100
PU-242	380000	Y	3.8	3.8	3.8	3.8	3.8	3.8
AM-241	433	Y	196	235	274	410	844	2070
AM-242M	151	Y	21	21	21	21	21	20
AM-242	16	H	21	21	21	21	21	20
AM-243	7650	Y	89	89	89	89	89	89
CM-242	163	D	81000	62700	48600	19500	887	16
CM-243	32.0	Y	14	14	14	14	14	12
CM-244	18.1	Y	22400	22200	22100	21600	20000	15300
CM-245	8260	Y	4.3	4.3	4.3	4.3	4.3	4.3
CM-246	4710	Y	1.5	1.5	1.5	1.5	1.5	1.5
SUM ACT			291000	238000	223000	190000	157000	116000
TOTALS			1.09E+7	6.40E+6	4.63E+6	2.46E+6	1.06E+6	429000

REFERENCE LWR - FIRST PU-RECYCLE
19 % OF FISSILE CHARGE IS LWR PLUTONIUM
BURN-UP 34000 MWD/T HM, SPECIFIC POWER 29.5 MW/T, FLUX 2.66E+13 N/SEC*CM**2

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                                        * FUEL  THERMAL DECAY POWER
                                        * LWR  FIRST PU-RECYCLE
                                        * BURN-UP 34000 MWD/T HM
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TABLE 10 NUCLIDE THERMAL POWER OF SPENT LWR FUEL (FIRST PU-RECYCLE)
(WATTS/T HM - FUEL DECAY TIMES AFTER REACTOR DISCHARGE

NUCLIDE	HALF-LIFE	30 DAYS	90 DAYS	150 DAYS	1 YEAR	3 YEARS	10 YEARS
SUM FP (INDIVIDUAL NUCLIDES SEE TABLE 6)		46900	27200	20200	10700	3580	1030
PU-238	88.9 Y	128	130	133	137	138	131
PU-239	24400 Y	10.2	10.2	10.2	10.2	10.2	10.2
PU-240	6760 Y	17.9	17.9	17.9	17.9	18.1	18.5
PU-241	14.6 Y	6.2	6.1	6.1	5.9	5.4	3.9
AM-241	433 Y	6.5	7.8	9.1	13.7	28.2	68.9
AM-243	7650 Y	3.2	3.2	3.2	3.2	3.2	3.2
CM-242	163 D	3000	2310	1790	718	32.7	0.6
CM-244	18.1 Y	783	778	774	756	700	536
SUM ACT		3960	3270	2750	1660	937	773
TOTALS		50900	30500	23000	12400	4520	1800

REFERENCE LWR - FIRST PU-RECYCLE
19 % OF FISSILE CHARGE IS LWR PLUTONIUM
BURN-UP 34000 MWD/T HM, SPECIFIC POWER 29.5 MW/T, FLUX 2.66E+13 N/SEC*CM**2

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* FUEL RADIOACTIVITY
* LWR  SECOND PU-RCYCLE
* BURN-UP 34000 MWD/T HM
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TABLE 11 NUCLIDE RADIOACTIVITY OF SPENT LWR FUEL (SECOND PU-RECYCLE)
(CURIES/T HM - FUEL DECAY TIMES AFTER REACTOR DISCHARGE)

NUCLIDE	HALF-LIFE		30 DAYS	90 DAYS	150 DAYS	1 YEAR	3 YEARS	10 YEARS
SUM FP (SINGLE NUCLIDES SEE TABLE 5)			1.06E+7	6.15E+6	4.41E+6	2.26E+6	805000	313000
TH-234	24.1	D	0.3	0.3	0.3	0.3	0.3	0.3
PA-233	27.4	D	0.3	0.3	0.3	0.3	0.3	0.3
PA-234M	1.8	M	0.3	0.3	0.3	0.3	0.3	0.3
U-234	247000	Y	0.7	0.7	0.7	0.7	0.7	0.8
U-236	2.39E+7	Y	0.2	0.2	0.2	0.2	0.2	0.2
U-237	7.6	D	30100	67	3.8	3.5	3.2	2.3
U-238	4.91E+9	Y	0.3	0.3	0.3	0.3	0.3	0.3
NP-237	2.13E+6	Y	0.3	0.3	0.3	0.3	0.3	0.3
NP-239	2.4	D	2630	132	132	132	132	132
PU-236	2.8	Y	0.4	0.4	0.4	0.3	0.2	0.03
PU-238	88.9	Y	4210	4310	4380	4530	4560	4320
PU-239	24400	Y	329	329	329	329	329	329
PU-240	6760	Y	584	584	585	587	594	615
PU-241	14.6	Y	154000	153000	152000	147000	134000	96100
PU-242	380000	Y	4.8	4.8	4.8	4.8	4.8	4.8
AM-241	433	Y	213	253	243	434	882	2140
AM-242M	151	Y	23	23	23	23	23	22
AM-242	16	H	23	23	23	23	23	22
AM-243	7650	Y	132	132	132	132	132	132
CM-242	163	D	90000	69700	54000	21700	985	18
CM-243	32.0	Y	16.5	16.5	16.4	16.2	15.5	13.3
CM-244	18.1	Y	37400	37200	36900	36100	33500	25600
CM-245	8260	Y	7.4	7.4	7.4	7.4	7.4	7.4
CM-246	4710	Y	2.7	2.7	2.7	2.7	2.7	2.7
SUM ACT			320000	266000	248000	211000	175000	130000
TOTALS			1.09E+7	6.42E+6	4.66E+6	2.47E+6	980000	443000

REFERENCE LWR SECOND PU-RECYCLE
19 % OF FISSILE CHARGE IS FIRST PU-RECYCLE PLUTONIUM
BURN-UP 34000 MWD/T HM, SPECIFIC POWER 29.5 MW/T, FLUX 2.61E+13 N/SEC*CM**2

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* WASTE ELEMENT QUANTITIES
* LWR  EQ. URANIUM CYCLE
* BURNUP  34000 MWD/T HM
* REPROCESSED AFTER 150 DAYS
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TABLE 12 WASTE ELEMENT QUANTITIES OF SPENT LWR FUEL REPROCESSED 150 DAYS AFTER REACTOR DISCHARGE
ONLY THOSE ELEMENTS ARE LISTET WHICH CHANGE WEIGHT MORE THAN 10 PERCENT WITHIN THE FIRST FEW HUNDRED YEARS. OTHER ELEMENTS SEE TABLE 1
1 % PU AND 1 % U LOST TO HAW
(GRAMS/T HM - WASTE DECAY TIMES)

ELEMENT	1 Y	3 Y	10 Y	100 Y	600 Y	10000 Y
CS	2720	2600	2370	1490	1370	1370
SR	897	871	790	404	357	357
BA	1520	1630	1860	2740	2870	2870
SM	858	890	927	912	892	891
PM	79.7	46.9	7.4			
GD	117	123	136	168	169	169
EU	188	183	172	162	182	183
PU	96.1	98.6	103	116	114	116
AM	154	154	156	154	122	42.5
CM	37.0	33.4	26.1	3.3	2.4	1.1
ZR	3770	3790	3870	4260	4310	4300
NB	0.3					
SB	16.3	14.0	11.0	10.4	10.4	10.4

REFERENCE LWR - EQUILIBRIUM FUEL CYCLE
3.3 % ENRICHED URANIUM
BURN-UP 34000 MWD/T HM, SPECIFIC POWER 29.5 MW/T, FLUX 2.90E+13 N/SEC*CM**2

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* WASTE  RADIOACTIVITY
* LWR  EQ. URANIUM FUEL CYCLE
* BURN-UP 34000 MWD/T HM
* REPROCESSED AFTER 150 DAYS
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TABLE 13 WASTE RADIOACTIVITY OF SPENT LWR FUEL REPROCESSED 150 DAYS AFTER REACTOR DISCHARGE
1 % PU AND 1 % U LOST TO HAW
(CURIES/T HM - WASTE DECAY TIMES)

NUCLIDE	HALF-LIFE	1 Y	3 Y	10 Y	100 Y	600 Y	10000 Y
H-3	12.3 Y	674	602	406	2.5		
KR-85	10.8 Y	10500	9240	5900	18		
CS-134	2.1 Y	160000	81200	7620			
CS-135	3.0*E+6 Y	0.3	0.3	0.3	0.3	0.3	0.3
CS-137	30.0 Y	107000	102000	87100	10900	0.1	
BA-137M	2.6 M	100000	95700	81400	10200	0.1	
SR-90	28.1 Y	76400	72700	61200	6640	0.3	
Y-90	64.0 H	76400	72700	61200	6640	0.3	
CE-144	284 D	312000	52400	102			
PR-144	17.3 M	312000	52400	102			
PM-147	2.6 Y	74000	43600	6840			
SM-151	87.2 Y	1260	1240	1170	573	11	
EU-152	12.0 Y	12	11	7.1	0.04		
EU-154	16.0 Y	6950	6380	4710	9.5		
EU-155	1.8 Y	4580	2130	146			
ZR-93	1.50E+6 Y	1.9	1.9	1.9	1.9	1.9	1.9
NB-93M	13.6 Y	0.28	0.44	0.89	1.9	1.9	1.9
ZR-95	65.2 D	5510	2.3				
NB-95	35.0 D	12200	4.9				
TC-99	210000 Y	15	15	15	15	15	14
RU-106	1.0 Y	210000	52700	422			
RH-106	30.0 S	210000	52700	422			
PD-107	7.00E+6 Y	0.12	0.12	0.12	0.12	0.12	0.12
AG-110M	253 D	944	128	0.12			
AG-110	24.4 S	123	17	0.02			
CD-113M	14.0 Y	11	9.6	6.8	0.08		
SN-126	100000 Y	0.6	0.6	0.6	0.6	0.6	0.5
SB-126M	19 M	0.6	0.6	0.6	0.6	0.6	0.5
SB-126	12.4 D	0.6	0.6	0.6	0.6	0.6	0.5
SB-125	2.7 Y	6330	3790	628			
SE-79	65000 Y	0.4	0.4	0.4	0.4	0.4	0.4
TE-125M	58.1 D	2620	1570	260			
TE-127M	109 D	599	5.8				
TE-127	9.4 H	592	5.7				
J-129	1.7*E+7 Y	0.04	0.04	0.04	0.04	0.04	0.04
U-234	247000 Y			0.01	0.03	0.06	0.06
NP-237	2.13*E+6 Y	0.35	0.35	0.35	0.36	0.38	0.39
NP-239	2.4 D	20	20	20	20	19	8.2
PU-238	88.9 Y	106	124	118	62	2.3	
PU-239	24400 Y	3.2	3.2	3.2	3.3	3.5	5.7
PU-240	6760 Y	5.1	5.7	7.2	12	12	4.4
PU-241	14.6 Y	1010	922	661	9.6	0.4	0.2
PU-242	380000 Y	0.02	0.02	0.02	0.02	0.02	0.02
AM-241	433 Y	163	166	173	169	76	0.2
AM-242M	151 Y	9.7	9.6	9.3	6.2	0.6	
AM-242	16 H	9.7	9.6	9.3	6.2	0.6	
AM-243	7650 Y	20	20	20	20	19	8.2
CM-242	163 D	4070	190	7.7	5.1	0.5	
CM-243	32.0 Y	4.0	3.9	3.3	0.47		
CM-244	18.1 Y	2680	2490	1900	60		
CM-245	8260 Y	0.41	0.41	0.41	0.41	0.39	0.18
CM-246	4710 Y	0.08	0.08	0.08	0.08	0.08	0.02
SUM FP		1690000	704000	320000	35100	32	20.5
SUM ACT		8110	3960	2940	376	135	27.9
TOTALS		1698000	708000	322900	35500	167	48

REFERENCE LWR - EQUILIBRIUM FUEL CYCLE
3.3 % ENRICHED URANIUM
BURN-UP 34000 MWD/T HM, SPECIFIC POWER 29.5 MW/T, FLUX 2.90E+13 N/SEC*CM**2

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* WASTE  THERMAL POWER
* LWR  EQ. URANIUM FUEL CYCLE
* BURN-UP 34000 MWD/T HM
* REPROCESSED AFTER 150 DAYS
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TABLE 14 WASTE NUCLIDE THERMAL POWER OF SPENT LWR FUEL
REPROCESSED 150 DAYS AFTER REACTOR DISCHARGE
1 % PU AND 1 % U LOST TO HAW
(WATTS/T HM - WASTE DECAY TIMES AFTER PROCESSING)

NUCLIDE	HALF-LIFE	1 Y	3 Y	10 Y	100 Y	600Y	10000 Y
H-3	12.3 Y	0.024	0.021	0.014			
KR-85	10.8 Y	17	15	9.6	0.03		
CS-134	2.1 Y	1690	861	81			
CS-137	30.0 Y	175	167	142	18		
BA-137M	2.6 M	394	376	320	40		
SR-90	28.1 Y	100	95	80	8.7		
Y-90	64.0 H	450	428	360	39		
CE-144	284 D	255	43	0.08			
PR-144	17.3 M	2410	406	0.8			
PM-147	2.6 Y	38.2	22.5	3.5			
SM-151	87.2 Y	2.2	2.2	2.1	1.0	0.02	
EU-152	12.0 Y	0.2	0.2	0.1			
EU-154	16.0 Y	57	52	39	0.8		
EU-155	1.8 Y	3.9	1.8	0.1			
TC-99	210000 Y	0.01	0.01	0.01	0.01	0.01	0.01
RU-106	1.0 Y	12.4	3.1	0.025			
RH-106	30.0 S	2200	554	4.4			
AG-110M	253 D	15.9	2.2	0.002			
SB-126M	19 M	0.004	0.004	0.004	0.004	0.004	0.004
SB-126	12.4 D	0.007	0.007	0.007	0.007	0.007	0.007
SB-125	2.7 Y	25.7	15.4	2.6			
TE-125M	58.1 D	4.5	2.7	0.45	0.003		
NP-237	2.13E+6 Y	0.010	0.010	0.010	0.010	0.011	0.012
NP-239	2.4 D	0.027	0.027	0.027	0.027	0.026	0.011
PU-238	88.9 Y	3.50	4.09	3.92	2.04	0.075	
PU-239	24400 Y	0.10	0.10	0.10	0.10	0.11	0.18
PU-240	6760 Y	0.16	0.18	0.23	0.38	0.36	0.14
PU-241	14.6 Y	0.042	0.038	0.027			
AM-241	433 Y	5.44	5.53	5.76	5.64	2.55	0.006
AM-242	16 H	0.013	0.013	0.013	0.008	0.001	
AM-243	7650 Y	0.74	0.74	0.74	0.74	0.70	0.30
CM-242	163 D	150	7.0	0.28	0.19	0.019	
CM-243	320. Y	0.15	0.14	0.22	0.017		
CM-244	18.1 Y	93.9	87.0	66.5	2.12		
CM-245	8260 Y	0.013	0.013	0.013	0.013	0.012	0.006
CM-246	4710 Y	0.003	0.003	0.003	0.003	0.003	0.001
SUM FP		7960	3050	1050	107	0.04	0.02
SUM ACT		254	105	78	11	3.9	0.65
TOTALS		8220	3160	1130	118	4.0	0.7

REFERENCE LWR - EQUILIBRIUM FUEL CYCLE
3.3 % ENRICHED URANIUM
BURN-UP 34000 MWD/T HM, SPECIFIC POWER 29.5 MW/T, FLUX 2.90E+13 N/SEC*CM**2

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* WASTE  RADIOACTIVITY
* LWR  EQ. URANIUM FUEL CYCLE
* HIGH BURN-UP 45300 MWD/T HM
* REPROCESSED AFTER 150 DAYS
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TABLE 15 WASTE RADIOACTIVITY OF SPENT LWR FUEL (HIGH BURNUP)
REPROCESSED 150 DAYS AFTER REACTOR DISCHARGE
1 % PU AND 1 % U LOST TO HAW
(CURIES/T HM - WASTE DECAY TIMES AFTER REPROCESSING)

NUCLIDE	HALF-LIFE	1 Y	3 Y	10 Y	100 Y	600 Y	10000 Y
H-3	12.3 Y	866	773	521	3.3		
KR-85	10.8 Y	14300	12600	8040	25		
CS-134	2.1 Y	239000	122000	11400			
CS-135	3.00E+6 Y	0.4	0.4	0.4	0.4	0.4	0.4
CS-137	30.0 Y	142000	136000	115000	14400	0.14	
BA-137M	2.6 M	133000	127000	108000	13500	0.13	
SR-90	28.1 Y	105000	100000	84200	9150	0.04	
Y-90	64.0 H	105000	100000	84200	9150	0.04	
CE-144	284 D	382000	64200	125			
PR-144	17.3 H	382000	64200	125			
PM-147	2.6 Y	82200	48400	7600			
SM-151	87.2 Y	1540	1520	1430	700	13	
EU-152	12.0 Y	13	12	7.9	0.04		
EU-154	16.0 Y	9970	9140	6750	137		
EU-155	1.8 Y	6690	3110	213			
ZR-93	1.50E+6 Y	2.6	2.6	2.6	2.6	2.6	2.6
NB-93M	13.6 Y	0.4	0.6	1.2	2.6	2.6	2.6
ZR-95	65.2 D	6450	2.7				
NB-95	35.0 D	14300	5.8				
TC-99	210000 Y	19	19	19	19	19	19
RU-106	1.0 Y	244000	61500	491			
RH-106	30.0 S	244000	61500	491			
PD-107	7.00E+6 Y	0.14	0.14	0.14	0.14	0.14	0.14
AG-110M	253 D	1230	166	0.2			
AG-110	24.4 S	160	22	0.02			
CD-113M	14.0 Y	15.3	13.8	9.8	0.1		
SN-126	100000 Y	0.7	0.7	0.7	0.7	0.7	0.7
SB-126M	19 M	0.7	0.7	0.7	0.7	0.7	0.7
SB-126	12.4 D	0.7	0.7	0.7	0.7	0.7	0.7
SB-125	2.7 Y	7700	4610	764			
SE-79	65000 Y	0.6	0.6	0.6	0.6	0.6	
TE-125M		3190	1910	316			
TE-127M	109 D	696	6.7				
TE-127	9.4 H	688	6.6				
J-129	1.70E+6 Y	0.05	0.05	0.05	0.05	0.05	0.05
U-234	247000 Y						
NP-237	2.13E+6 Y	0.54	0.54	0.54	0.55	0.57	0.59
NP-239	2.4 D	30	30	30	30	28	12
PU-238	88.9 Y	147	170	162	84	2.8	
PU-239	24000 Y	3.2	3.2	3.2	3.3	3.7	6.8
PU-240	6760 Y	5.6	6.5	9.2	17.7	17.0	6.0
PU-241	14.6 Y	1120	1020	733	11	0.7	0.6
PU-242	380000 Y	0.02	0.02	0.02	0.02	0.02	0.02
AM-241	433 Y	178	181	188	185	84	0.4
AM-242M	151 Y	10.8	10.7	10.3	6.9	0.7	
AM-242	16 H	10.8	10.7	10.3	6.9	0.7	
AM-243	7650 Y	30	30	30	30	28	12
CM-242	163 D	5190	241	8.5	5.6	0.6	
CM-243	32.0 Y	5.8	5.5	4.8	0.7		
CM-244	18.1 Y	4670	4330	3310	105		
CM-245	8260 Y	0.8	0.8	0.8	0.8	0.7	0.3
CM-246	4710 Y	0.2	0.2	0.2	0.2	0.2	0.04
SUM FP		2130000	918000	430000	47100	41	
SUM ACT		11400	6040	4500	488	169	39
TOTALS		2140000	924000	434500	47600	210	

REFERENCE LWR - EQUILIBRIUM FUEL CYCLE
4.5 % ENRICHED URANIUM
BURN-UP 45300 MWD/T HM, SPECIFIC POWER 35.4 MW/T, FLUX 2.99E+13 N/SEC*CM**2

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* WASTE  THERMAL POWER
* LWR  EQ. URANIUM FUEL CYCLE
* HIGH BURN-UP 45300 MWD/T HM
* REPROCESSED AFTER 150 DAYS
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TABLE 16 WASTE NUCLIDE THERMAL POWER OF SPENT LWR FUEL (HIGH BURNUP)
REPROCESSED 150 DAYS AFTER REACTOR DISCHARGE
1 % PU AND 1 % U LOST TO HAW
(WATTS/T HM - WASTE DECAY TIMES AFTER REPROCESSING)

NUCLIDE	HALF-LIFE	1 Y	3 Y	10 Y	100 Y	600 Y	10000 Y
H-3	12.3 Y	0.031	0.027	0.18			
KR-85	10.8 Y	23	20	13	0.04		
CS-134	2.1 Y	2520	1290	121			
CS-137	30.0 Y	232	222	188	24		
BA-137M	2.6 M	524	500	426	53		
SR-90	28.1 Y	137	131	110	12		
Y-90	64.D H	618	588	495	54		
CE-144	284 D	312	53	0.1			
PR-144	17.3 M	2951	497	1.0			
PM-147	2.6 Y	42	24	3.9			
SM-151	87.2 Y	2.7	2.7	2.6	1.2	0.02	
EU-152	12.0 Y	0.2	0.2	0.1			
EU-154	16.0 Y	82	75	56	1.1		
EU-155	1.8 Y	5.7	2.6	0.1			
TC-99	210000 Y	0.01	0.01	0.01	0.01	0.01	0.01
RU-106	1.0 Y	14	3.6	0.029			
RH-106	30.0 S	2560	644	5.1			
AG-110M	253 D	21	2.9	0.003			
SB-125	2.7 Y	31	19	3.2			
SB-126M	19 M	0.005	0.005	0.005	0.005	0.005	0.005
SB-126	12.4 D	0.009	0.009	0.009	0.009	0.009	0.008
TE-125M	58.1 D	5.5	3.3	0.55	0.004		
NP-237	2.13E+6 Y	0.016	0.016	0.016	0.016	0.017	0.018
NP-239	2.4 D	0.040	0.040	0.040	0.040	0.039	0.016
PU-238	88.9 Y	4.9	5.6	5.4	2.8	0.10	
PU-239	24400 Y	0.10	0.10	0.10	0.10	0.11	0.18
PU-240	6760 Y	0.17	0.19	0.25	0.41	0.38	0.15
PU-241	14.6 Y	0.046	0.042	0.030			
AM-241	433 Y	5.9	6.1	6.3	6.2	2.8	0.007
AM-242	16 H	0.014	0.014	0.014	0.009	0.001	
AM-243	7650 Y	1.1	1.1	1.1	1.1	1.0	0.4
CM-242	163 D	191	8.9	0.36	0.24	0.02	
CM-243	32 Y	0.22	0.20	0.17	0.02		
CM-244	18.1 Y	164	152	116	3.7		
CM-245	8260 Y	0.025	0.025	0.025	0.024	0.023	0.011
CM-246	4710 Y	0.006	0.006	0.006	0.006	0.005	0.002
SUM FP		10030	3980	1410	144	0.05	0.03
SUM ACT		357	160	119	14	4.8	1.0
TOTALS		10400	4140	1530	158	4.9	1.1

REFERENCE LWR - EQUILIBRIUM FUEL CYCLE
4.5 % ENRICHED URANIUM
BURN-UP 45300 MWD/T HM, SPECIFIC POWER 35.4 MW/T, FLUX 2.99E+13 N/SEC*CM**2

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* WASTE  RADIOACTIVITY
* LWR  FIRST PU-RECYCLE
* BURN-UP 34000 MWD/T HM
* REPROCESSED AFTER 150 D
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TABLE 17 WASTE NUCLIDE RADIOACTIVITY OF SPENT LWR FUEL (FIRST PU-RECYCLE)
REPROCESSED 150 DAYS AFTER REACTOR DISCHARGE
1 % PU AND 1 % U LOST TO HAW
(CURIES/T HM - WASTE DECAY TIMES)

NUCLIDE	HALF-LIFE	1 Y	3 Y	10 Y	100 Y	600 Y	10000 Y
H-3	12.3 Y	729	651	439	2.8		
KR-85	10.8 Y	9500	8350	5330	16.5		
CS-134	2.1 Y	154000	78300	7340			
CS-135	3.00E+6 Y	0.3	0.3	0.3	0.3	0.3	0.3
CS-137	30.0 Y	108000	103000	87800	11000	0.1	
BA-137M	2.6 M	101000	96500	82100	10300	0.1	
SR-90	28.1 Y	68300	65000	54700	5940	0.03	
Y-90	64.0 H	68300	65000	54700	5940	0.03	
CE-144	284 D	302000	50900	99			
PR-144	17.3 M	302000	50900	99			
PM-147	2.6 Y	75400	44400	6970			
SM-151	87.2 Y	1300	1280	1210	592	11	
EU-152	12.0 Y	12.9	11.5	7.7	0.04		
EU-154	16.0 Y	7460	6840	5050	102		
EU-155	1.8 Y	4900	2280	156			
ZR-93	1.50E+6 Y	1.8	1.8	1.8	1.8	1.8	1.8
NB-93M	13.6 Y	0.3	0.4	0.8	1.8	1.8	1.8
ZR-95	65.2 D	5430	2.3				
NB-95	35.0 D	12000	4.9				
TC-99	210000 Y	15	15	15	15	15	14
RU-106	1.0 Y	239000	60200	481			
RH-106	30.0 S	239000	60200	481			
PD-107	7.00E+6 Y	0.15	0.15	0.15	0.15	0.15	0.15
AG-110M	253 D	1240	168	0.15			
AG-110	24.4 S	161	22	0.02			
CD-113M	14.0 Y	14.2	12.8	9.1	0.1		
SN-126	100000 Y	0.7	0.7	0.7	0.7	0.7	0.6
SB-126M	19 M	0.7	0.7	0.7	0.7	0.7	0.6
SB-126	12.4 D	0.7	0.7	0.7	0.7	0.7	0.6
SB-125	2.7 Y	7340	4390	728			
SE-79	65000 Y	0.4	0.4	0.4	0.4	0.4	0.4
TE-125M	58.1 D	3040	1820	302			
TE-127M	109 D	624	6.0				
TE-127	9.4 H	617	5.9				
J-129	1.70E+7 Y	0.04	0.04	0.04	0.04	0.04	0.04
U-234	247000 Y				0.06	0.12	0.12
NP-237	2.13E+6 Y	0.27	0.27	0.27	0.27	0.31	0.34
NP-239	2.4 D	89	89	89	88	84	36
PU-238	88.9 Y	231	276	265	138	5.0	
PU-239	24400 Y	3.3	3.3	3.3	3.5	4.7	16.6
PU-240	6760 Y	7.8	12.2	24.6	63.2	61.2	23.3
PU-241	14.6 Y	1400	1270	915	17.	4.1	1.9
PU-242	38000 Y	0.04	0.04	0.04	0.04	0.04	0.05
AM-241	433 Y	276	279	288	277	127	1.9
AM-242M	151 Y	20.8	20.6	20.0	13.2	1.4	
AM-242	16 H	20.8	20.6	20.0	13.2	1.4	
AM-243	7650 Y	89	89	89	88	84	36
CM-242	163 D	10300	477	16	1.1	1.1	
CM-243	32.0 Y	14	13	12	1.6		
CM-244	18.1 Y	21300	19700	15100	480		
CM-245	8260 Y	4.3	4.3	4.3	4.2	4.1	1.9
CM-246	4710 Y	1.5	1.5	1.5	1.5	1.4	0.3
SUM FP		1720000	700000	308000	33800	32.5	2.1
SUM ACT		33700	22300	16800	1200	380	119
TOTALS		1754000	722000	325000	35000	413	121

REFERENCE LWR - FIRST PU-RECYCLE
19 % OF FISSILE CHARGE IS LWR PLUTONIUM
BURN-UP 34000 MWD/T HM, SPECIFIC POWER 29.5 MW/T, FLUX 2.66E+13 N/SEC*CM**2

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                                        * WASTE  THERMAL POWER
                                        * LWR  FIRST PU-RECYCLE
                                        * BURN-UP 34000 MWD/T HM
                                        * REPROCESSED AFTER 150 DAYS
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TABLE 18 WASTE NUCLIDE THERMAL POWER OF SPENT LWR FUEL (FIRST PU-RECYCLE)
REPROCESSED 150 DAYS AFTER REACTOR DISCHARGE
1 % PU AND 1 % U LOST TO HAW
(WATTS/T HM - WASTE DECAY TIMES AFTER REPROCESSING)

NUCLIDE	HALF-LIFE	1 Y	3 Y	10 Y	100 Y	600 Y	10000 Y
SUM FP (SINGLE NUCLIDES SEE TABLE 14)		8090	3040	1000	103	0.04	0.02
NP-237	2.13E+6 Y	0.01	0.01	0.01	0.01	0.01	0.01
NP-239	2.4 D	0.12	0.12	0.12	0.12	0.11	0.05
PU-238	88.9 Y	7.7	9.2	8.8	4.6	0.2	
PU-239	24000 Y	0.10	0.10	0.10	0.11	0.15	0.5
PU-240	6760 Y	0.25	0.38	0.77	2.0	1.9	0.7
PU-241	14.6 Y	0.06	0.04	0.01			
AM-241	433 Y	9.2	9.3	9.6	9.2	4.2	0.06
AM-243	7650 Y	3.2	3.2	3.2	3.2	3.1	1.3
CM-242	163 D	379	18	0.6	0.4	0.04	
CM-243	32.0 Y	0.5	0.5	0.4	0.06		
CM-244	18.1 Y	744	690	527	17		
CM-245	8260 Y	0.13	0.13	0.13	0.13	0.13	0.06
CM-246	4710 Y	0.05	0.05	0.05	0.05	0.05	0.01
SUM ACT		1150	730	551	37	9.9	2.8
TOTALS		9240	3770	1550	140	9.9	2.8

REFERENCE LWR - FIRST PU-RECYCLE
19 % OF FISSILE CHARGE IS LWR PLUTONIUM
BURN-UP 34000 MWD/T HM, SPECIFIC POWER 29.5 MW/T, FLUX 2.66E+13 N/SEC*CM**2

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* WASTE  RADIOACTIVITY
* LWR  SECOND PU-RCYCLE
* BURN-UP 34000 MWD/T HM
* REPROCESSED AFTER 150 DAYS
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TABLE 19 WASTE NUCLIDE RADIOACTIVITY OF SPENT LWR FUEL (SECOND PU-RECYCLE)
REPROCESSED 150 DAYS AFTER REACTOR DISCHARGE
1 % PU AND 1 % U LOST TO HAW
(CURIES/T HM - WASTE DECAY TIMES)

NUCLIDE	HALF-LIFE		1 Y	3 Y	10 Y	100 Y	600 Y	10000 Y
SUM FP			1.71E+6	6.99E+5	3.07E+5	33800	33	21
(SINGLE NUCLIDE ACTIVITY SEE TABLE 17)								
U-234	247000	Y		0.01	0.01	0.07	0.13	0.13
NP-237	2.13E+6	Y	0.26	0.26	0.26	0.27	0.30	0.34
NP-239	2.4	D	132	132	132	131	125	53
PU-238	88.9	Y	256	307	294	153	5.5	
PU-239	24000	Y	3.3	3.3	3.3	3.7	5.4	23.5
PU-240	6760	Y	9.6	17	37	102	99	38
PU-241	14.6	Y	1450	1320	946	21	7.1	3.2
PU-242	380000	Y	0.05	0.05	0.05	0.05	0.05	0.07
AM-241	433	Y	295	298	308	295	137	3.2
AM-242M	151	Y	23	23	22	15	1.5	
AM-242	16	H	23	23	22	15	1.5	
AM-243	7650	Y	132	132	132	131	125	53
CM-242	163	D	11400	530	18	12	1.2	
CM-243	32.0	Y	16	15	13	1.9		
CM-244	18.1	Y	35600	32900	25200	802		
CM-245	8260	Y	7.4	7.4	7.4	7.4	7.1	3.2
CM-246	4710	Y	2.7	2.7	2.7	2.7	2.5	0.6
SUM ACT			49300	35700	27100	1690	518	179
TOTALS			1.75E+6	735000	334000	35500	551	200

REFERENCE LWR SECOND PU-RECYCLE
19 % OF FISSILE CHARGE IS FIRST PU-RECYCLE PLUTONIUM
BURN-UP 34000 MWD/T HM, SPECIFIC POWER 29.5 MW/T, FLUX 2.61E+13 N/SEC*CM**2

* CLADDING RADIOACTIVITY
* LWR EQ. URANIUM FUEL CYCLE
* BURN-UP 34000 MWD/T HM
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TABLE 20 NUCLIDE RADIOACTIVITY OF FUEL ELEMENT CLADDING AND STRUCTURAL PARTS (0.414 T/T HM)
(CURIES/T HEAVY METAL CHARGED TO REACTOR - DECAY TIMES AFTER REACTOR DISCHARGE)

NUCLIDE	HALF-LIFE	30 DAYS	90 DAYS	150 DAYS	1 YEAR	3 YEARS	10 YEARS
SR-89	52.1 D	41	18	8.2	0.5		
Y-91	90.0 D	113	56	27	2.2		
ZR-93	1.50E+6 Y	0.17	0.17	0.17	0.17	0.17	0.17
NB-93M	13.6 Y	0.01	0.01	0.02	0.02	0.04	0.08
ZR-95	65.2 D	33400	17600	9280	937	0.4	
NB-95	35.0 D	41600	28400	17000	1950	0.8	
CR-51	27.8 D	4640	1040	233	1.1		
MN-54	303 D	126	110	96	59	11	0.03
FE-55	2.6 Y	1080	1040	992	848	497	77
FE-59	45 D	60	24	9.4	0.3		
CO-58	71 D	4930	2750	1540	190	0.2	
CO-60	5.3 Y	70	68	67	62	48	19
NI-59	80000 Y	2.8	2.8	2.8	2.8	2.8	2.8
NI-63	92 Y	416	416	415	413	407	386
SN-117M	14.0 D	4300	221	11			
SN-119M	250 D	35	30	25	14	1.8	
SN-121M	76 Y	0.6	0.6	0.6	0.6	0.6	0.5
SB-125	2.7 Y	73	70	67	57	34	5.7
TE-125M	58.1 D	27	28	27	24	14	2.4
TOTALS		90800	51900	29800	4560	1020	494

NUCLIDE	HALF-LIFE	100 Y	600 Y	10000 Y	100000 Y
NI-59	80000 Y	2.8	2.8	2.6	1.2
NI-63	92 Y	195	4.5		
ZR-93	1.50E+6 Y	0.17	0.17	0.17	0.16
NB-93M	13.6 Y	0.17	0.17	0.17	0.16
TOTALS		199	7.7	2.9	1.5

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REFERENCE LWR - EQUILIBRIUM FUEL CYCLE
3.3 % ENRICHED URANIUM
BURN-UP 34000 MWD/T HM, SPECIFIC POWER 29.5 MW/T, FLUX 2.90E+13 N/SEC*CM**2
ZIRCALOY-4 FUEL ELEMENT CLADDING, STAINLESS STEEL AND INCONEL STRUCTURAL PARTS

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* CLADDING THERMAL POWER
* LWR EQ. URANIUM FUEL CYCLE
* BURN-UP 34000 MWD/T HM
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TABLE 21 NUCLIDE THERMAL POWER OF FUEL ELEMENT CLADDING AND STRUCTURAL PARTS (0.414 T/T HM)
(WATTS/T HM - DECAY TIMES AFTER REACTOR DISCHARGE)

NUCLIDE	HALF-LIFE	30 DAYS	90 DAYS	150 DAYS	1 YEAR	3 YEARS	10 YEARS
CR-51	27.8 D	21	4.6	1.0			
MN-54	303 D	1.0	0.9	0.8	0.5	0.09	
FE-55	2.6 Y	1.4	1.4	1.3	1.1	0.7	0.1
CO-58	71 D	67	38	21	2.6		
CO-60	5.3 Y	1.1	1.1	1.0	1.0	0.7	0.3
NI-63	92 Y	0.06	0.06	0.06	0.06	0.06	0.06
ZR-95	65.2 D	175	92	49	4.9		
NB-95	35.0 D	200	137	82	9.4		
SB-125	2.7 Y	0.3	0.3	0.3	0.2	0.1	0.02
TOTALS		476	276	156	20	1.7	0.5

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REFERENCE LWR - EQUILIBRIUM FUEL CYCLE
3.3 % ENRICHED URANIUM
BURN-UP 34000 MWD/T HM, SPECIFIC POWER 29.5 MW/T, FLUX 2.90E+13 N/SEC*CM**2
ZIRCALOY-4 FUEL ELEMENT CLADDING, STAINLESS STEEL AND INCONEL STRUCTURAL PARTS

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                                        * PHOTON RELEASE RATE
                                        * LWR  EQ. URANIUM CYCLE
                                        * BURNUP  34000 MWD/T HM
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TABLE 22 PHOTON RELEASE RATE OF FISSION PRODUCTS, ACTINIDES, AND CLADDING AND STRUCTURAL PARTS OF SPENT LWR FUEL (PHOTONS/SEC PER TON OF HEAVY METAL CHARGED TO REACTOR - FUEL DECAY TIMES AFTER REACTOR DISCHARGE)

E MEAN(MEV)	30 D	90 D	150 D	1 Y	3 Y	10 Y
FUEL ELEMENT CLADDING AND STRUCTURAL MATERIALS PHOTON RELEASE RATES (PHOTONS/SEC)						
0.30	1.69E+13	3.87E+12	9.49E+11	9.14E+10	5.22E+10	8.91E+09
0.63	3.58E+15	2.19E+15	1.25E+15	1.43E+14	1.44E+12	1.41E+11
1.10	8.27E+12	6.71E+12	6.01E+12	5.43E+12	4.00E+12	1.59E+12
1.55	1.31E+12	6.23E+11	4.00E+11	4.82E+10	3.80E+07	2.04E+04
1.99	1.38E+10	6.74E+09	3.37E+09	2.81E+08	6.12E+04	6.10E+02
2.38	1.17E+07	1.40E+05	1.68E+03			
TOTAL	3.61E+15	2.20E+15	1.26E+15	1.48E+14	5.50E+12	1.74E+12
FISSION PRODUCT PHOTON RELEASE RATES (PHOTONS/SEC)						
0.30	2.16E+16	1.05E+16	8.23E+15	4.80E+15	1.13E+15	1.80E+14
0.63	1.72E+17	1.02E+17	6.82E+16	2.88E+16	1.33E+16	4.13E+15
1.10	5.07E+15	1.99E+15	1.61E+15	1.10E+15	4.46E+14	1.43E+14
1.55	1.24E+16	1.05E+15	5.49E+14	3.75E+14	1.39E+14	1.10E+13
1.99	8.22E+14	3.39E+14	2.71E+14	1.62E+14	2.92E+13	1.25E+11
2.38	4.12E+14	4.54E+13	2.80E+13	1.82E+13	4.51E+12	3.54E+10
2.75	2.61E+12	2.33E+12	2.08E+12	1.39E+12	3.48E+11	2.78E+09
3.25	8.24E+10	7.36E+10	6.57E+10	4.38E+10	1.10E+10	8.80E+07
TOTAL	2.13E+17	1.16E+17	7.89E+16	3.53E+16	1.51E+16	4.46E+15
ACTINIDE PHOTON RELEASE RATES (PHOTONS/SEC)						
0.03	5.66E+14	1.38E+12	2.15E+11	3.17E+11	6.51E+11	1.59E+12
0.04	5.76E+13	6.32E+12	6.17E+12	5.98E+12	5.86E+12	5.84E+12
0.06	5.82E+14	3.71E+12	2.93E+12	4.24E+12	8.40E+12	2.01E+13
0.10	1.22E+12	7.26E+10	6.26E+10	4.69E+10	4.04E+10	5.22E+10
0.15	5.79E+13	4.43E+11	3.71E+11	3.62E+11	3.55E+11	3.52E+11
0.20	3.70E+14	9.36E+11	1.98E+11	1.95E+11	1.92E+11	1.83E+11
0.30	4.94E+13	2.08E+11	1.32E+11	1.32E+11	1.31E+11	1.28E+11
0.63	2.58E+12	7.67E+11	7.30E+11	6.54E+11	6.05E+11	6.02E+11
1.10	5.53E+11	1.54E+11	1.54E+11	1.54E+11	1.53E+11	1.53E+11
1.55	2.76E+08	2.54E+08	2.37E+08	2.00E+08	1.68E+08	1.34E+08
1.99	1.45E+08	1.34E+08	1.25E+08	1.05E+08	8.81E+07	7.00E+07
2.38	7.23E+07	6.64E+07	6.19E+07	5.20E+07	4.30E+07	3.29E+07
2.75	5.65E+07	5.77E+07	5.97E+07	7.14E+07	1.24E+08	2.33E+08
3.25	2.09E+07	1.92E+07	1.79E+07	1.50E+07	1.24E+07	9.50E+06
3.70	1.34E+07	1.23E+07	1.15E+07	9.66E+06	7.99E+06	6.10E+06
4.22	8.47E+06	7.78E+06	7.25E+06	6.09E+06	5.04E+06	3.85E+06
4.70	4.01E+06	3.68E+06	3.43E+06	2.88E+06	2.38E+06	1.82E+06
5.25	2.52E+06	2.32E+06	2.16E+06	1.81E+06	1.50E+06	1.15E+06
TOTAL	1.69E+15	1.40E+13	1.10E+13	1.21E+13	1.64E+13	2.90E+13

REFERENCE LWR - EQUILIBRIUM FUEL CYCLE
3.3 % ENRICHED URANIUM
BURN-UP 34000 MWD/T HM, SPECIFIC POWER 29.5 MW/T, FLUX 2.90E+13 N/SEC*CM**2

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                                        * NEUTRON SOURCE
                                        * LWR  EQ. URANIUM CYCLE
                                        * BURNUP  34000 MWD/T HM
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TABLE 23 SPONTANEOUS FISSION AND ALPHA-N NEUTRON SOURCE OF SPENT LWR FUEL (FUEL DECAY TIMES AFTER REACTOR DISCHARGE) AND WASTE OF LWR FUEL, REPROCESSED 150 DAYS AFTER DISCHARGE. (WASTE DECAY TIMES AFTER REPROCESSING) U-235 EQUILIBRIUM FUEL CYCLE AND FIRST PU-RECYCLE 1 % PU AND 1 % U LOST TO HAW

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U-235 EQUILIBRIUM FUEL CYCLE

SPONTANEOUS FISSION NEUTRON SOURCE IN DISCHARGED FUEL (NEUTRONS/SEC)

NUCLIDE	30 D	90 D	150 D	1 Y	3 Y	10 Y
PU-238	4.08E+05	4.12E+05	4.15E+05	4.21E+05	4.20E+05	3.98E+05
PU-240	2.07E+06	2.07E+06	2.07E+06	2.07E+06	2.07E+06	2.08E+06
PU-242	7.59E+05	7.59E+05	7.59E+05	7.59E+05	7.59E+05	7.59E+05
CM-242	1.90E+08	1.47E+08	1.14E+08	4.57E+07	2.09E+06	4.56E+04
CM-244	3.97E+08	3.95E+08	3.92E+08	3.84E+08	3.55E+08	2.72E+08
CM-246	2.54E+06	2.54E+06	2.54E+06	2.54E+06	2.54E+06	2.53E+06
CM-248	1.09E+04	1.09E+04	1.09E+04	1.09E+04	1.09E+04	1.09E+04
CF-250	5.51E+03	5.46E+03	5.41E+03	5.25E+03	4.72E+03	3.26E+03
CF-252	3.19E+05	3.06E+05	2.93E+05	2.51E+05	1.49E+05	2.37E+04
TOTAL	5.94E+08	5.48E+08	5.13E+08	4.36E+08	3.63E+08	2.78E+08

ALPHA-N NEUTRON SOURCE IN DISCHARGED FUEL (NEUTRON/SEC)

TOTAL	1.08E+08	8.67E+07	7.04E+07	3.70E+07	1.57E+07	1.47E+07

FIRST PU-RECYCLE

SPONTANEOUS FISSION NEUTRON SOURCE IN DISCHARGED FUEL (NEUTRONS/SEC)

PU-238	5.28E+05	5.40E+05	5.49E+05	5.66E+05	5.70E+05	5.41E+05
PU-240	2.45E+06	2.45E+06	2.45E+06	2.46E+06	2.48E+06	2.53E+06
PU-242	1.93E+06	1.93E+06	1.93E+06	1.93E+06	1.93E+06	1.93E+06
CM-242	4.80E+08	3.72E+08	2.88E+08	1.16E+08	5.26E+06	9.74E+04
CM-244	3.15E+09	3.13E+09	3.11E+09	3.04E+09	2.82E+09	2.16E+09
CM-246	4.43E+07	4.43E+07	4.43E+07	4.43E+07	4.43E+07	4.43E+07
CM-248	3.81E+05	3.81E+05	3.81E+05	3.81E+05	3.81E+05	3.81E+05
CF-250	2.63E+05	2.60E+05	2.58E+05	2.50E+05	2.25E+05	1.55E+05
CF-252	2.16E+07	2.07E+07	1.98E+07	1.70E+07	1.00E+07	1.61E+06
CF-254	1.36E+04	6.83E+03	3.43E+03	2.92E+02		
TOTAL	3.70E+09	3.57E+09	3.47E+09	3.23E+09	2.88E+09	2.21E+09

ALPHA-N NEUTRON SOURCE IN DISCHARGED FUEL (NEUTRONS/SEC)

TOTAL	3.00E+08	2.47E+08	2.05E+08	1.20E+08	6.25E+07	5.07E+07

WASTE NEUTRON SOURCE, U-235 EQUILIBRIUM FUEL CYCLE (NEUTRONS/SEC)

	INITIAL	1 Y	3 Y	5 Y	10 Y	100 Y
TOTAL SF	5.09E+08	4.05E+08	3.54E+08	3.27E+08	2.70E+08	1.11E+07
TOTAL ALPHA-N	6.32E+07	1.90E+07	7.21E+06	6.26E+06	5.27E+06	7.09E+05

WASTE NEUTRON SOURCE, FIRST PU-RECYCLE (NEUTRONS/SEC)

TOTAL SF	3.47E+09	3.12E+09	2.83E+09	2.62E+09	2.17E+09	1.12E+08
TOTAL ALPHA-N	1.96E+08	8.27E+07	5.03E+07	4.56E+07	3.78E+07	2.39E+06

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REFERENCE LWR - EQUILIBRIUM FUEL CYCLE
3.3 % ENRICHED URANIUM
BURN-UP 34000 MWD/T HM, SPECIFIC POWER 29.5 MW/T, FLUX 2.90E+13 N/SEC*CM**2

REFERENCE LWR - FIRST PU-RECYCLE
19 % OF FISSILE CHARGE IS LWR PLUTONIUM
BURN-UP 34000 MWD/T HM, SPECIFIC POWER 29.5 MW/T, FLUX 2.66E+13 N/SEC*CM**2

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TABLE 24 WASTE PRODUCTION OF A 1500 TONS PER YEAR REPROCESSING PLANT
(1 % U AND 1 % PU LOST TO HAW)

	1 Y	3 Y	10 Y	100 Y	600 Y	10000 Y
WASTE QUANTITY (BASED ON LWR FUEL - 34000 MWD/T HM) KILOGRAMS/1500 JATO						
U	14310	14310	14310	14310	14325	14415
NP	750	750	752	762	803	834
PU	144	148	155	174	171	171
AM	231	231	234	231	183	64
CM	56	50	39	5	4	1.6
SUM TU	1181	1179	1180	1172	1161	1074
SUM ACT	15490	15490	15490	15490	15490	15490
SUM FP	53850	53850	53850	53850	53850	53850
SUM HULLS	621000	621000	621000	621000	621000	621000
WASTE RADIOACTIVITY IN HAW (BASED ON LWR FUEL OF 34000 MWD/T HM) CURIES/1500 JATO						
SUM ACT	1.22E+7	5.94E+6	4.41E+6	5.64E+5	203000	41850
SUM F.P.	2.54E+9	1.06E+9	4.80E+8	5.27E+7	48000	30750
SUM HULLS	3.00E+6	1.43E+6	7.25E+5	2.99E+5	11500	4410
WASTE THERMAL POWER OF HAW (BASED ON LWR FUEL - 34000 MWD/T HM) WATTS/1500 JATO						
SUM ACT	3.81E+5	1.58E+5	1.17E+5	16500	5850	975
SUM F.P.	1.19E+7	4.58E+6	1.58E+6	161000	60	30
SUM HULLS	9180	2330	683	47	1	

ACCUMULATED HIGH ACTIVE WASTE
MEGA-CURIES

	1 Y	3 Y	5 Y	7 Y	10 Y
SUM ACT	12	26	37	47	60
SUM HULLS	3	6	9	11	13
SUM FP	2540	5100	6600	7800	9200

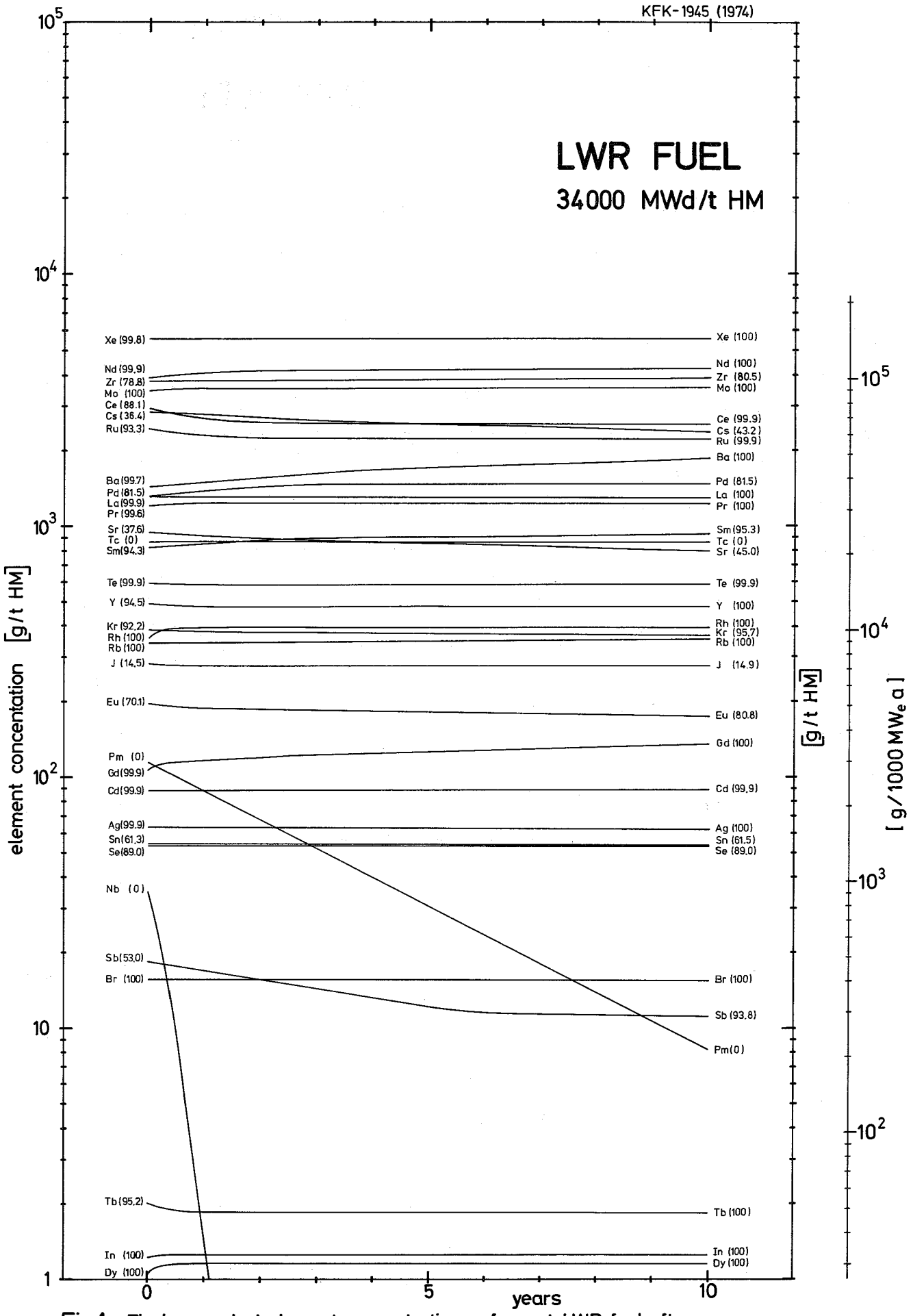

Fig.1 Fission product element concentrations of spent LWR fuel after reactor discharge. Numbers at element symbol give percentage of stable isotopes (left at 30 days cooling, right after 10 years).

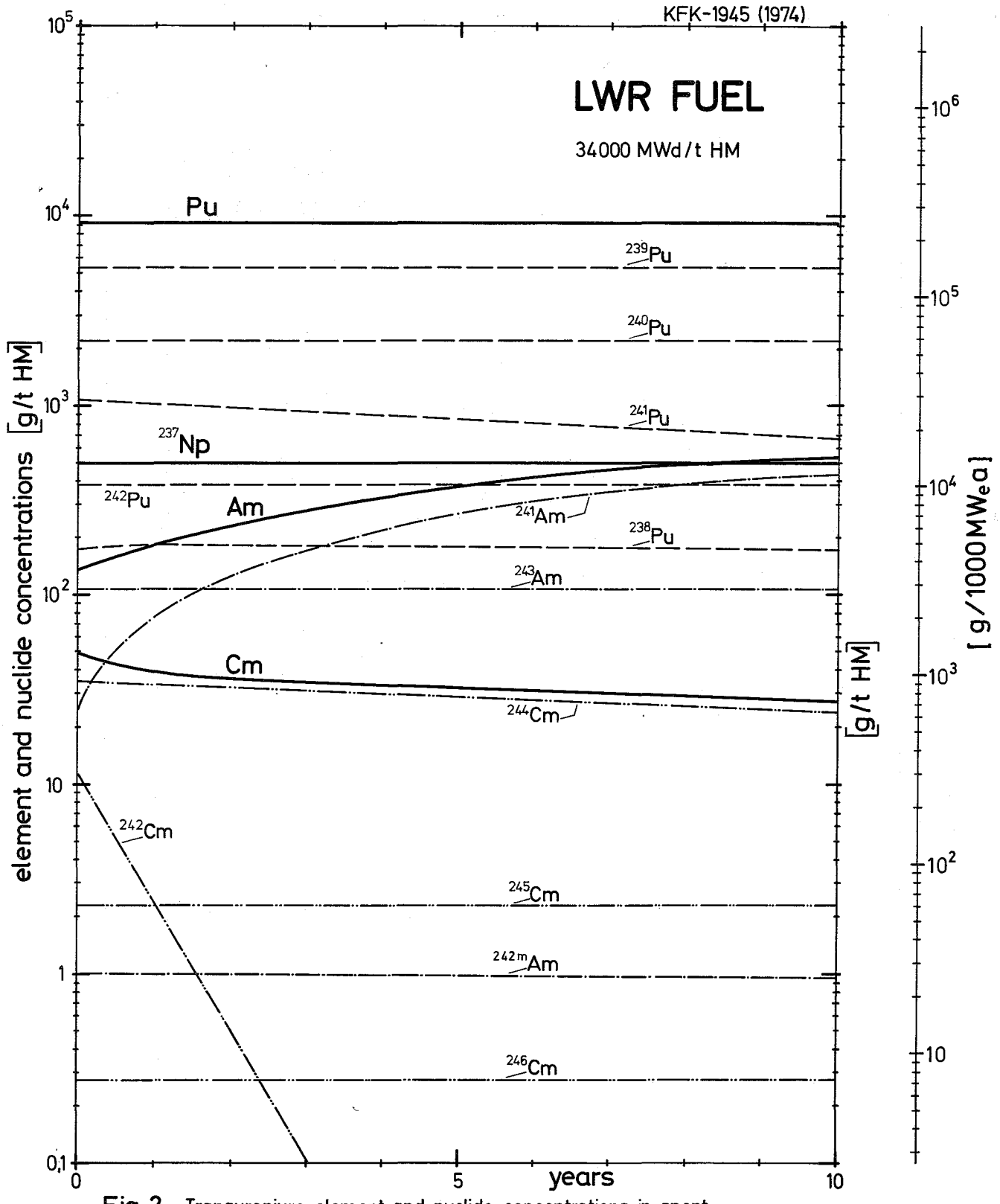

Fig. 2 Transuranium element and nuclide concentrations in spent LWR fuel after reactor discharge.

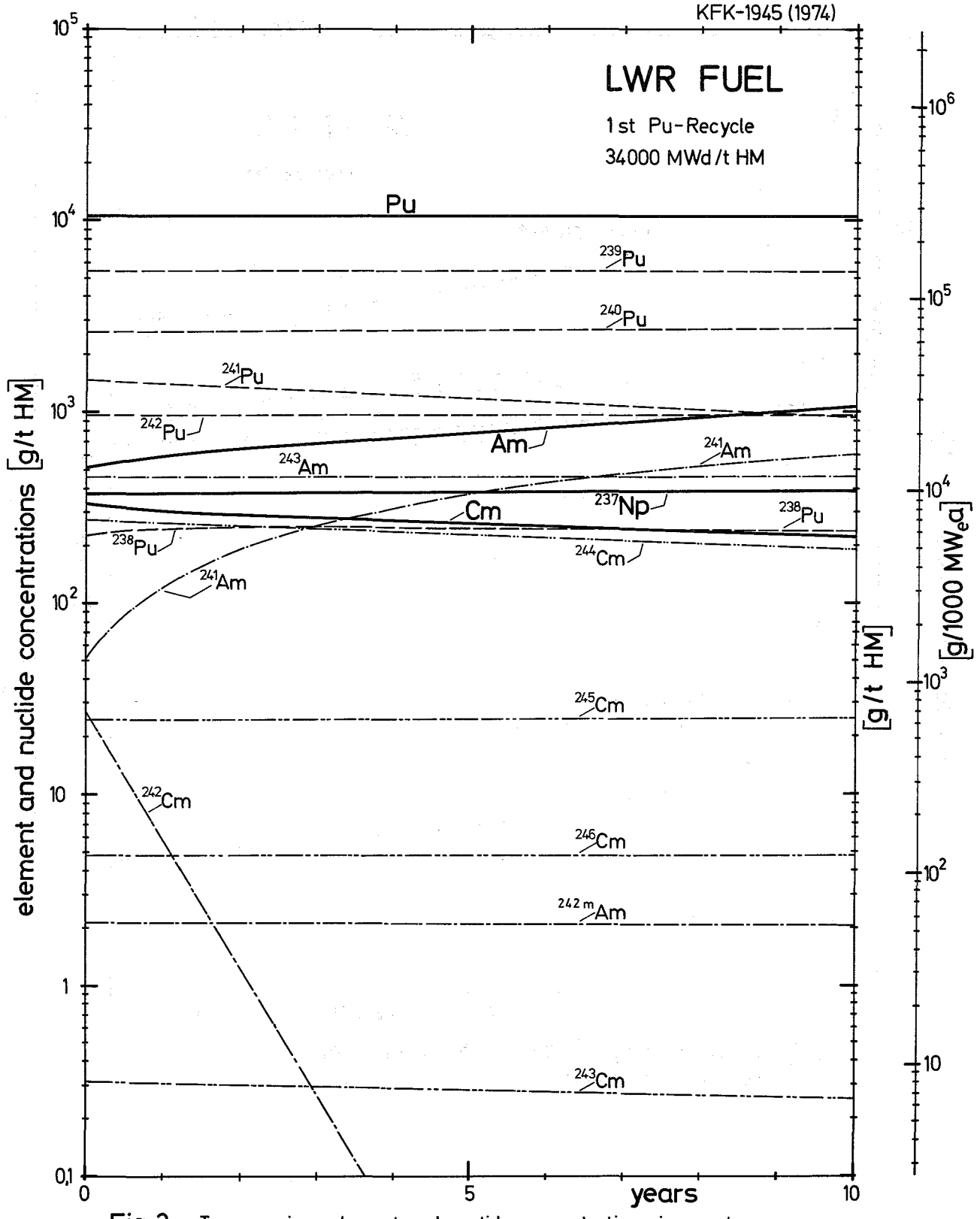

Fig. 3 Transuranium element and nuclide concentrations in spent LWR fuel, 1 st Pu-recycle, after reactor discharge.

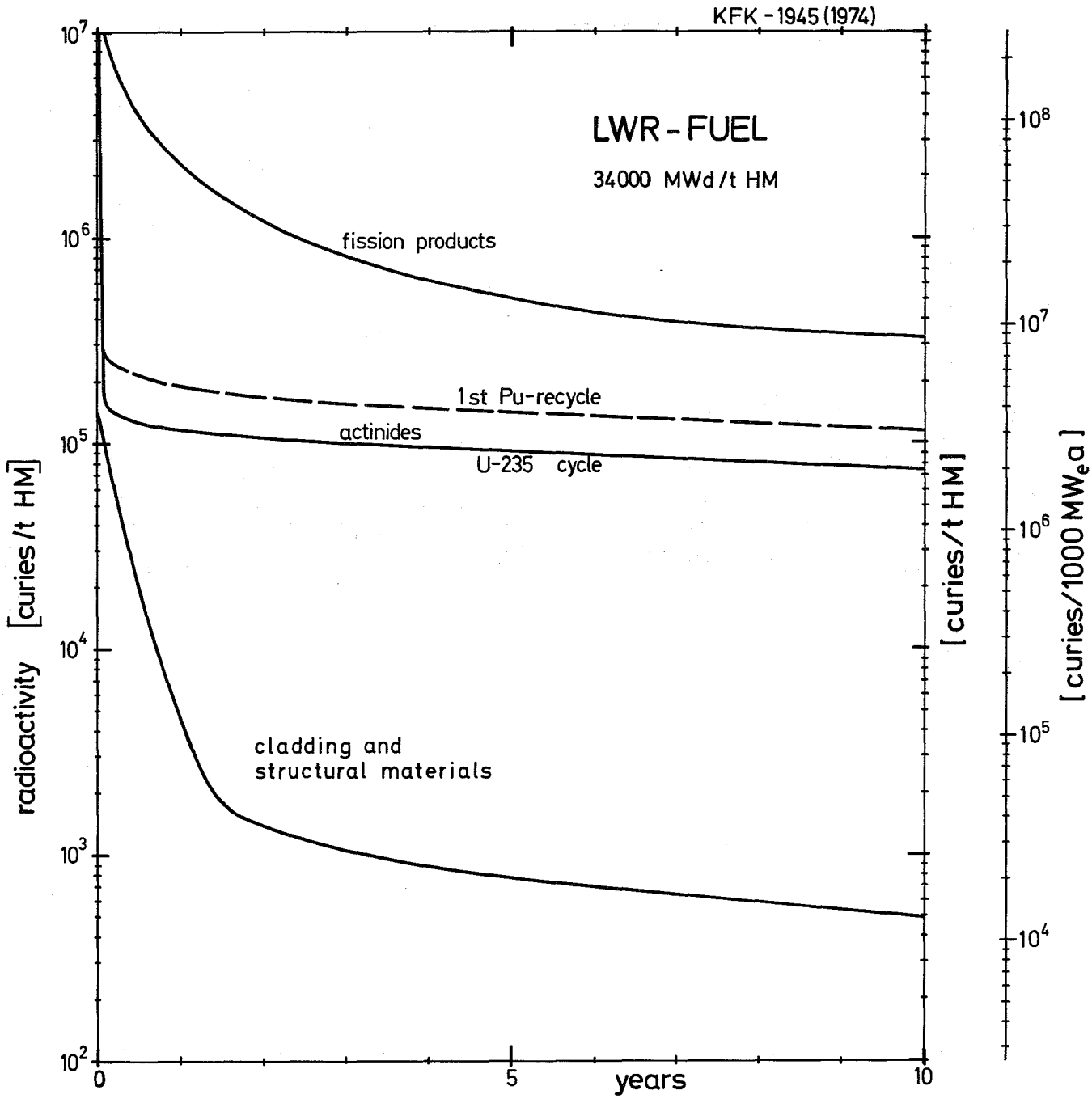

Fig.4 Radioactivity of spent LWR fuel after reactor discharge

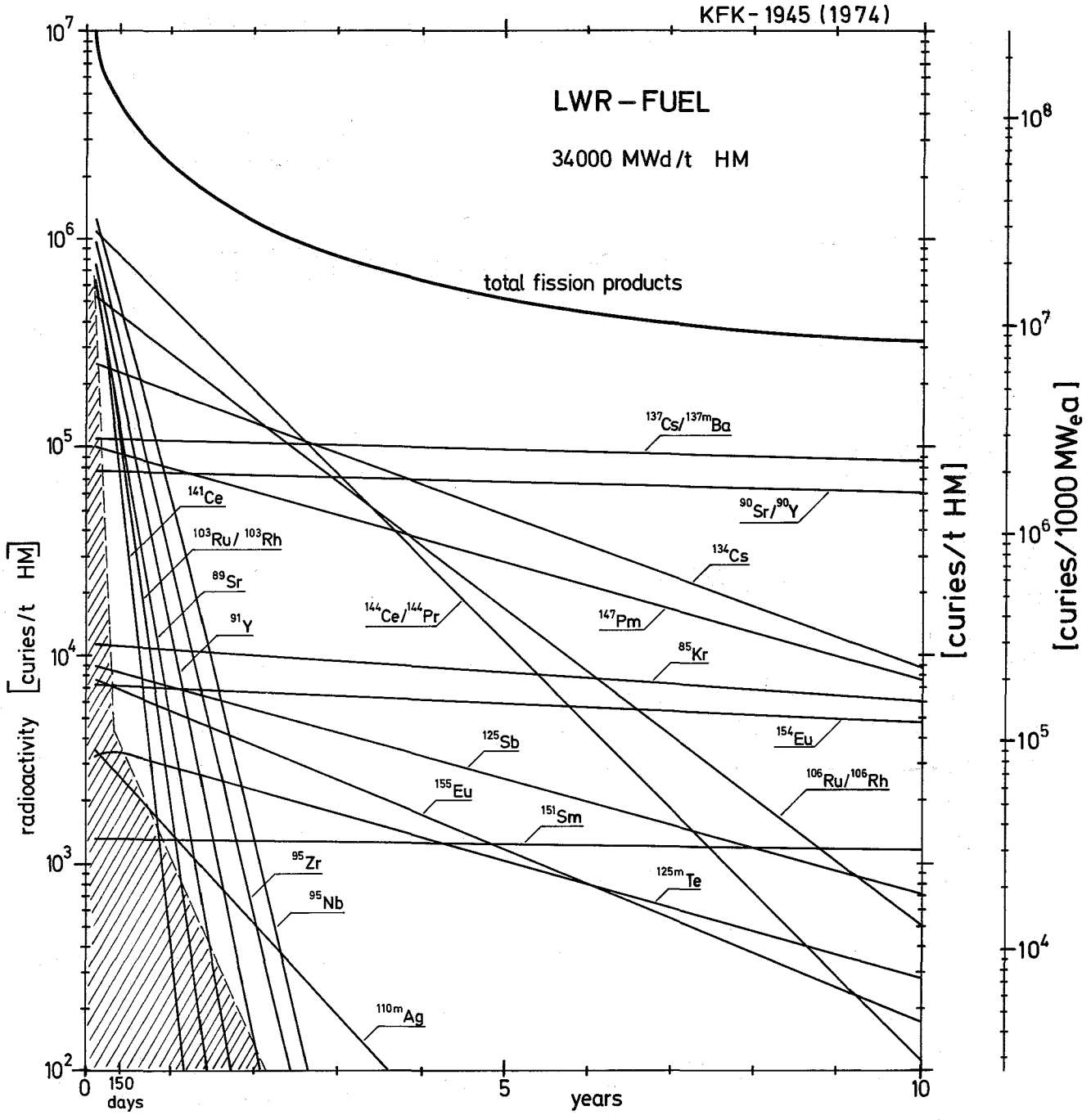

Fig. 5 Fission product nuclide radioactivity of spent LWR fuel after reactor discharge

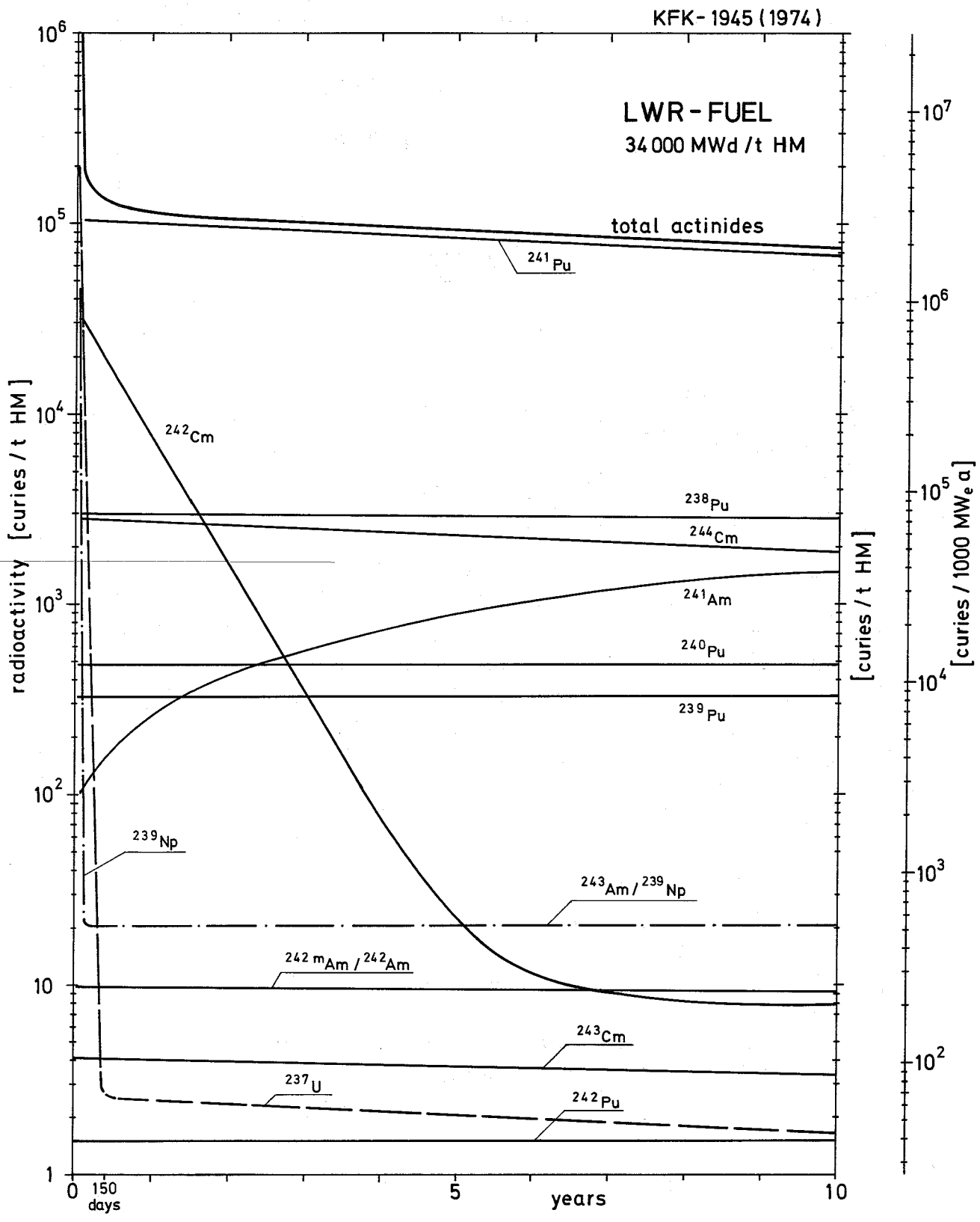

Fig.6 Actinide nuclide radioactivity in spent LWR fuel after reactor discharge

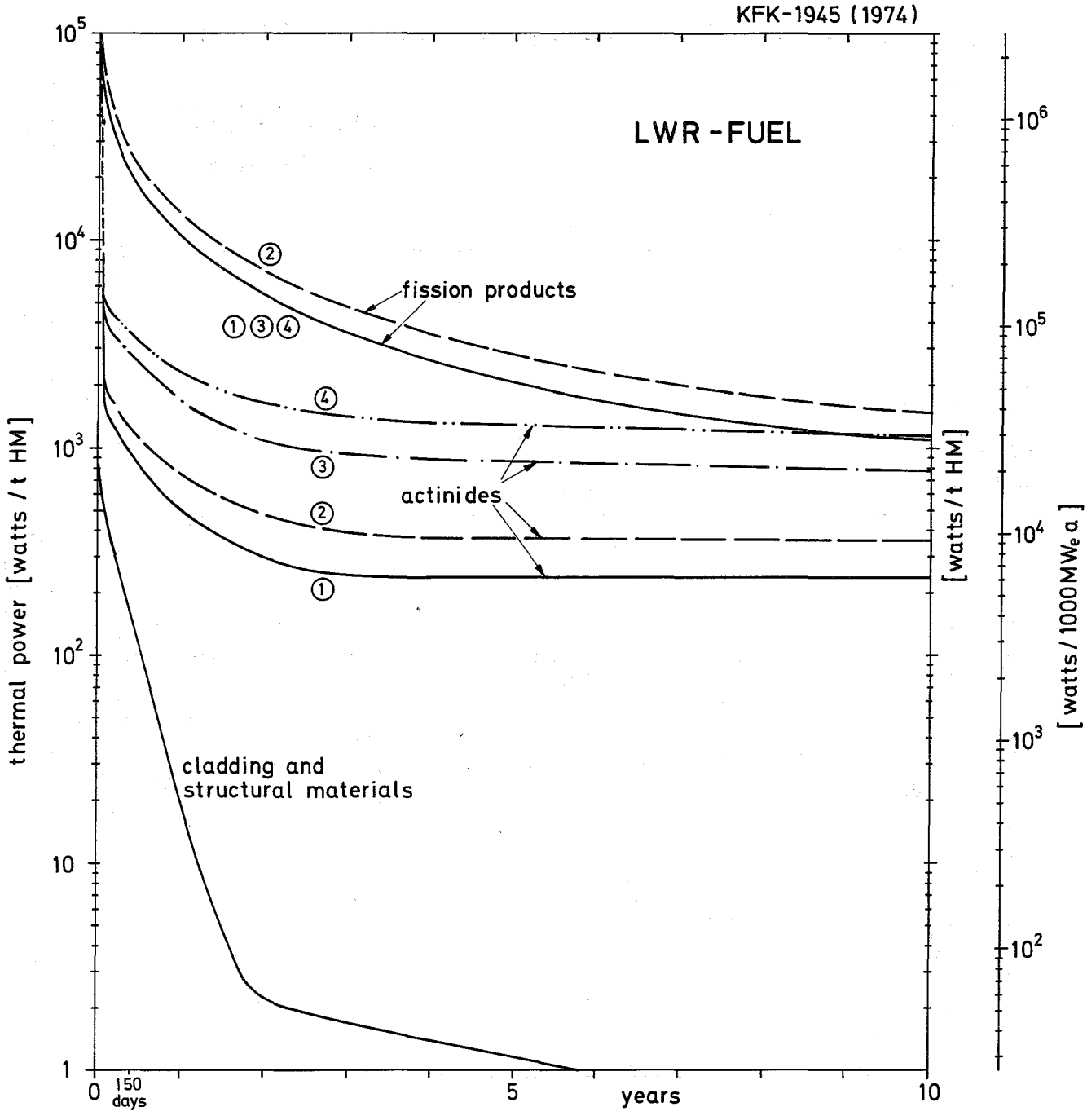

Fig. 7 Themal power of spent LWR fuel after reactor discharge

① U-235 cycle, 34000 MWd / t HM
② U-235 cycle, 45000 —— " ——
③ 1st Pu-recycle, 34000 —— " ——
④ 2nd Pu-recycle, 34000 —— " ——

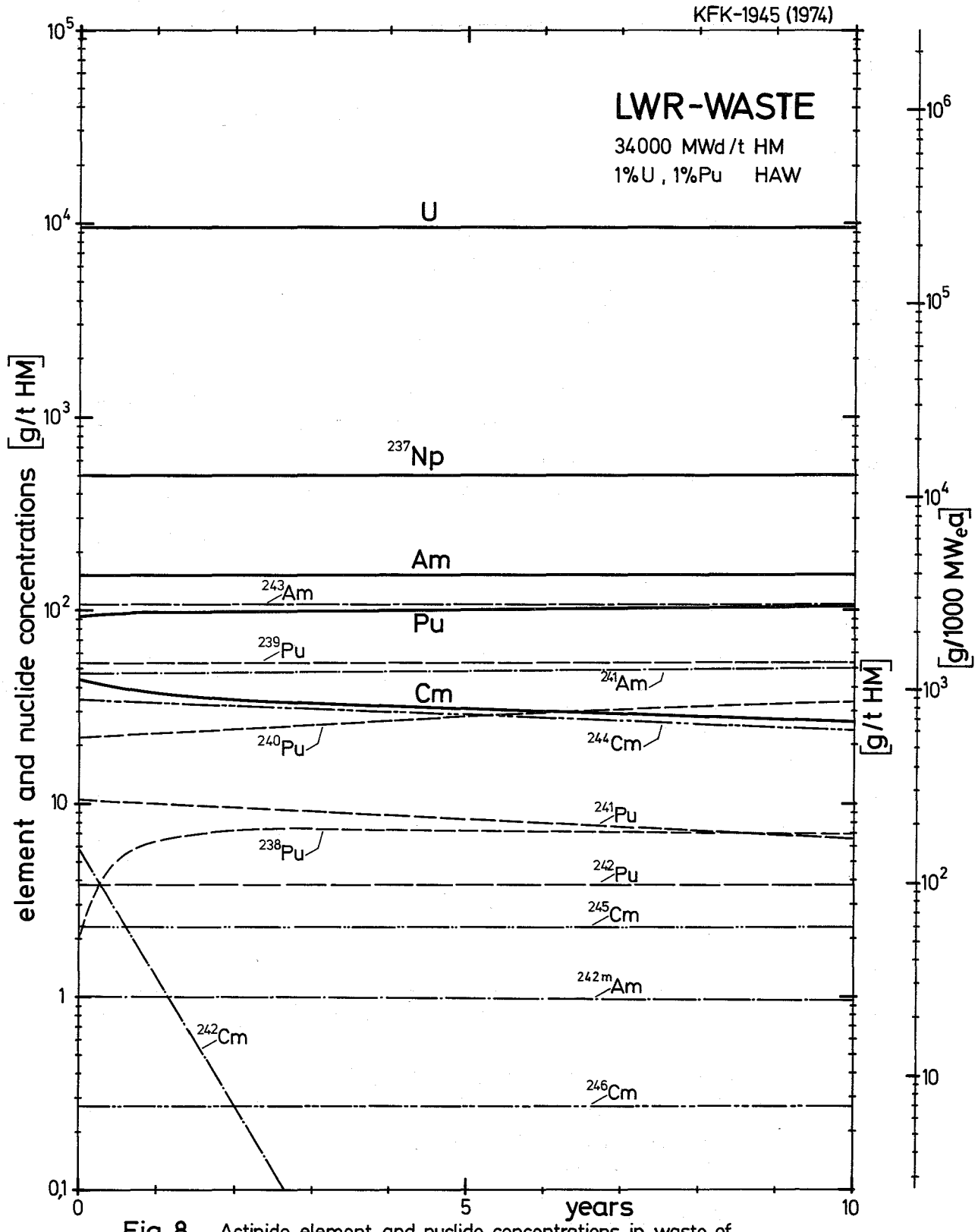

Fig. 8 Actinide element and nuclide concentrations in waste of spent LWR fuel reprocessed 150 days after reactor discharge. 1% U and 1% Pu lost into HAW.

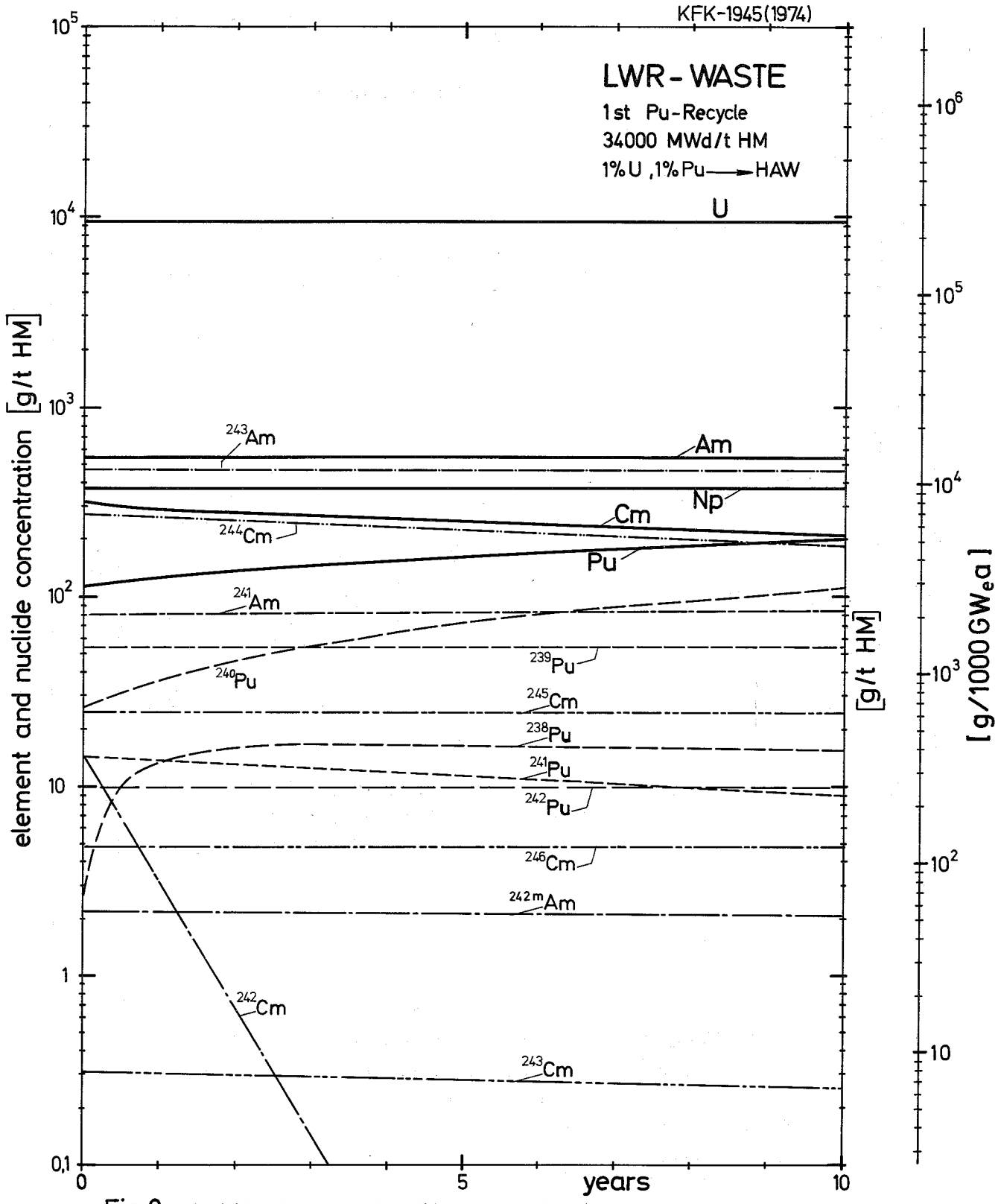

Fig.9 Actinide element and nuclide concentrations in waste of spent LWR fuel, 1st Pu-Recycle, reprocessed 150 days after reactor discharge. 1% U and 1% Pu lost into HAW.

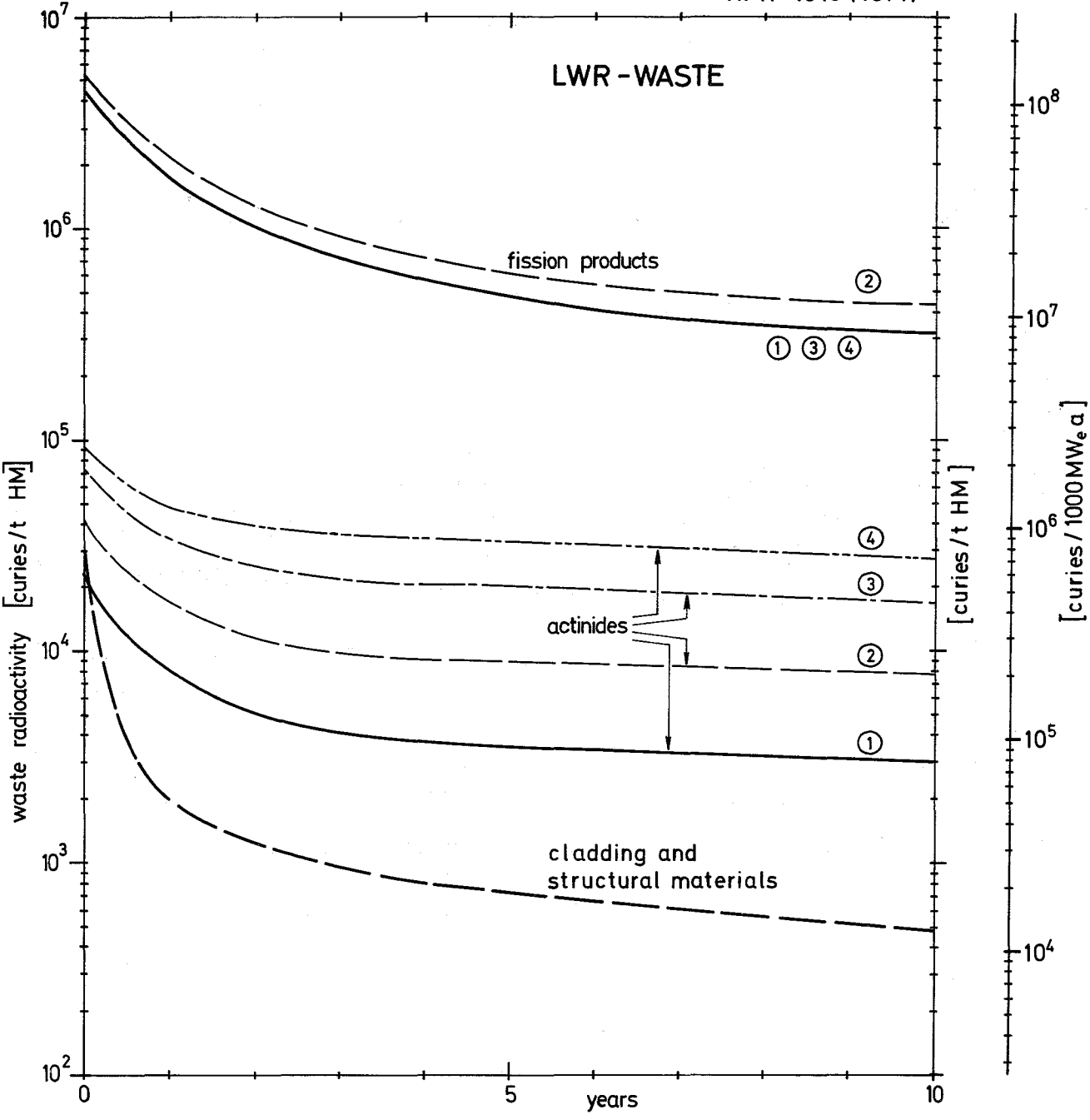

Fig.10 Waste radioactivity of LWR fuel reprocessed 150 days after reactor discharge

① U-235 cycle, 34000 MWd/t HM
② U-235 cycle, 45000 —— " ——
③ 1st Pu-recyle, 34000 —— " ——
④ 2nd Pu-recyle, 34000 —— " ——

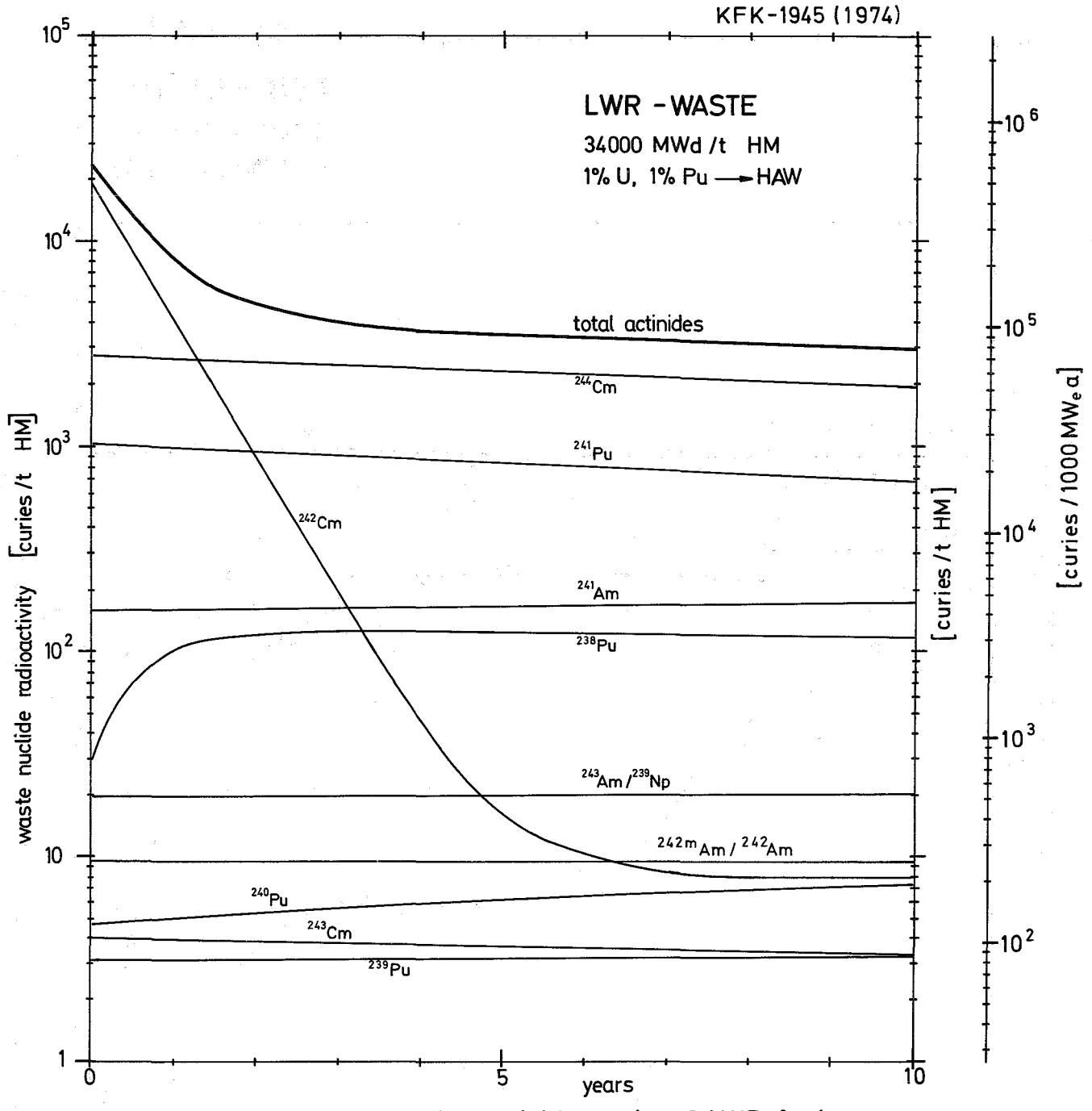

Fig.11 Waste nuclide radioactivity-actinides only-of LWR fuel reprocessed 150 days after reactor discharge

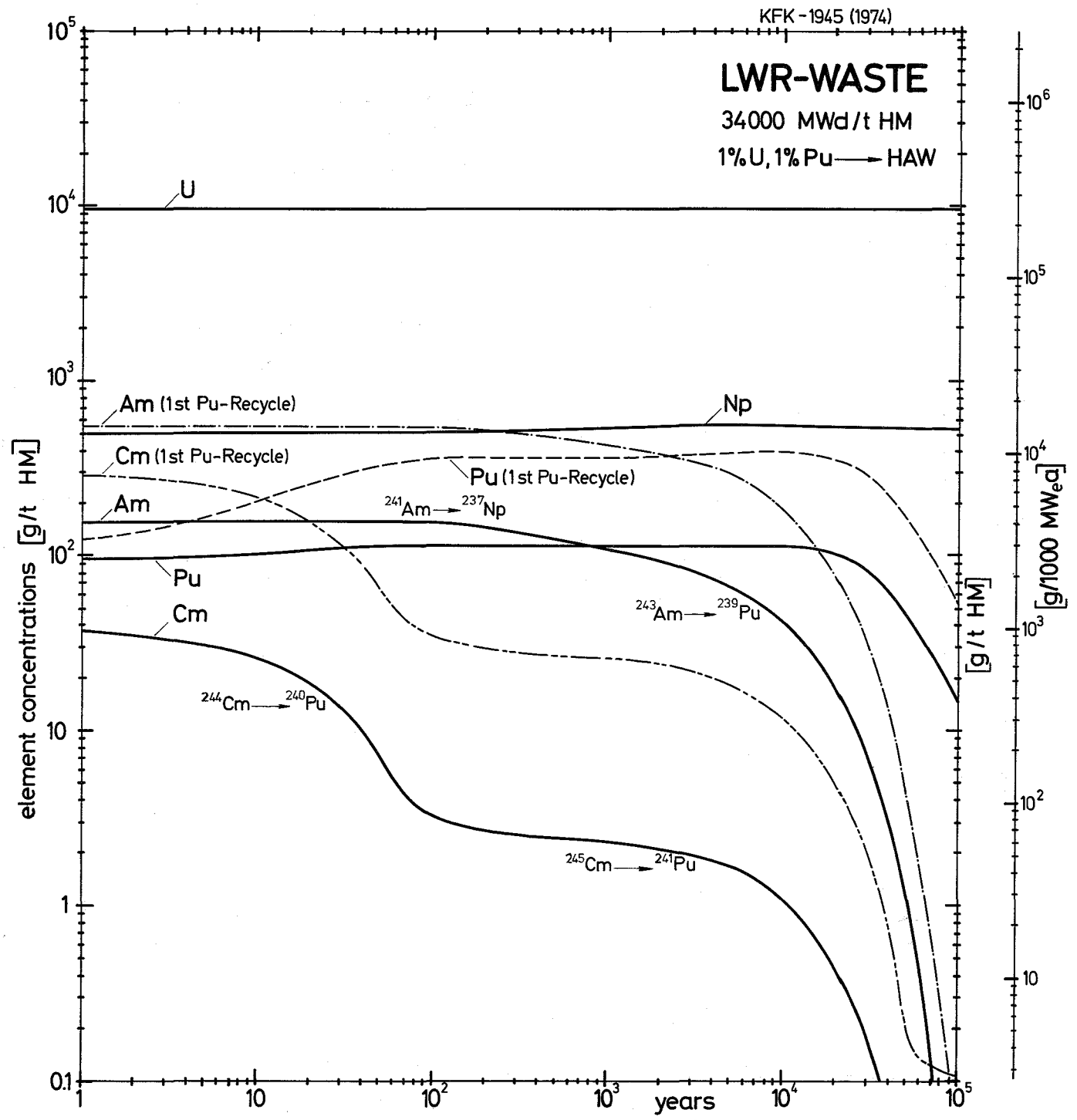

Fig.12 Waste actinide element concentrations of LWR fuel reprocessed 150 days after reactor discharge

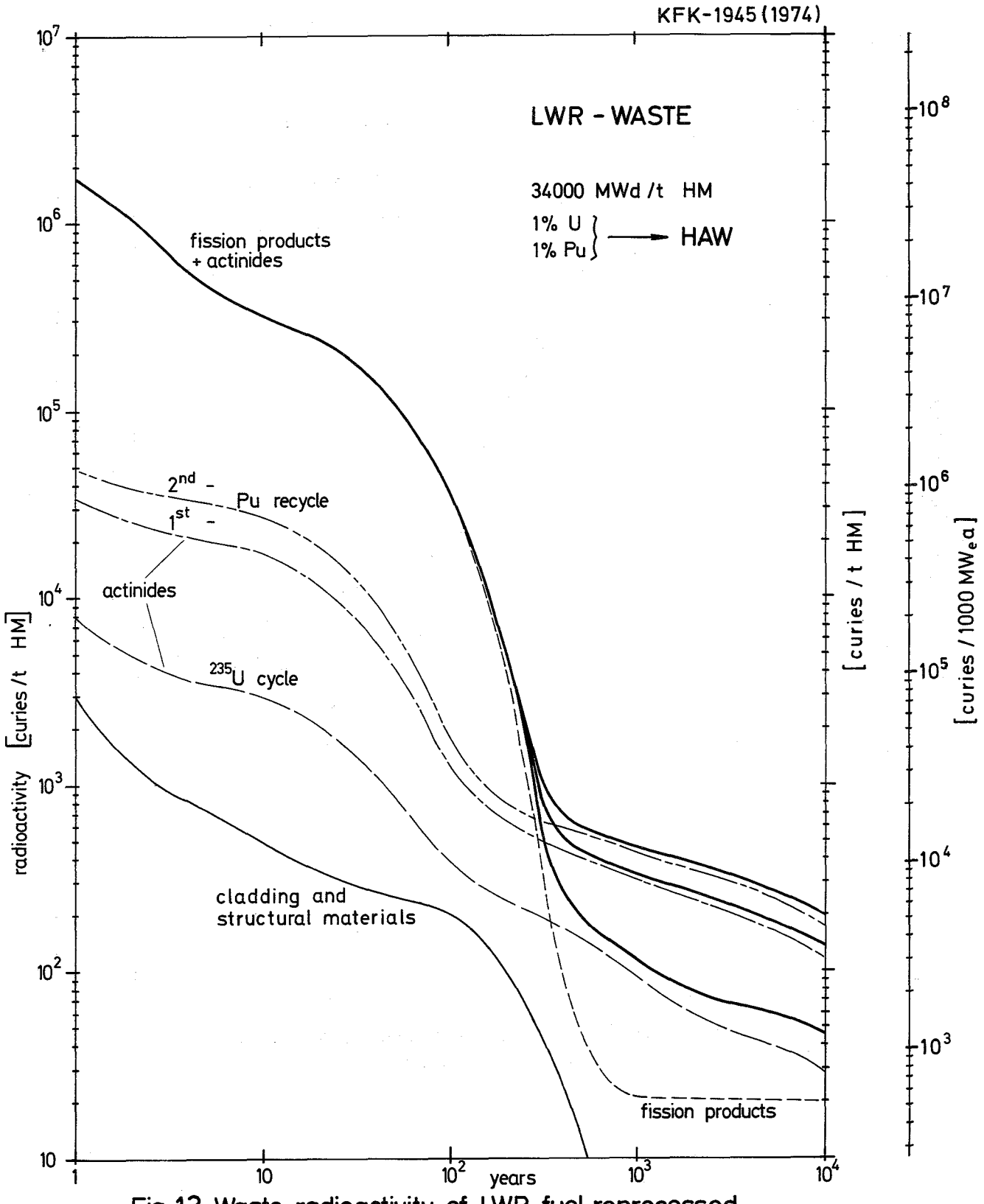

Fig. 13 Waste radioactivity of LWR fuel reprocessed 150 day after reactor discharge

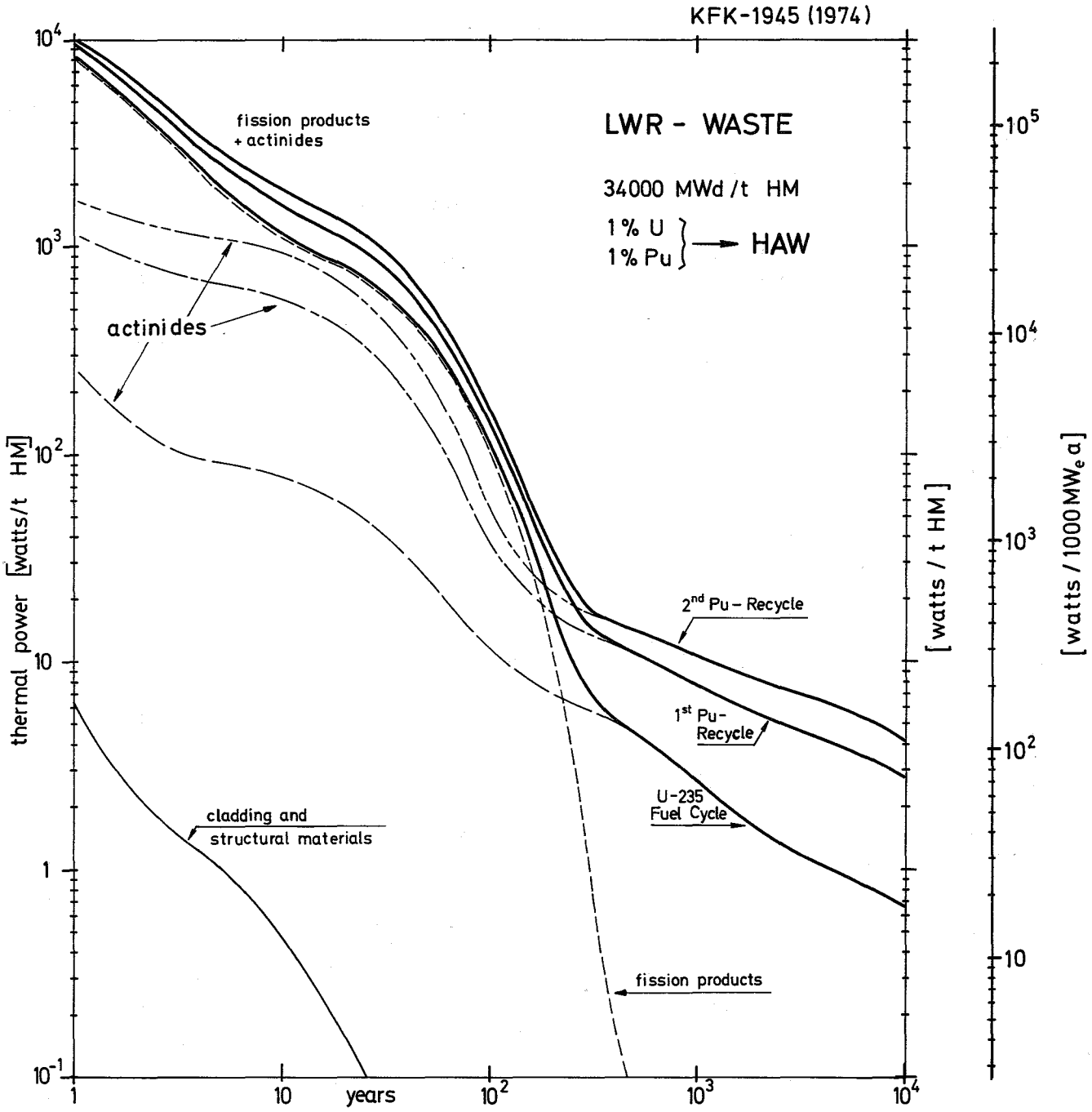

Fig.14 Waste thermal power of LWR fuel reprocessed 150 days after reactor discharge

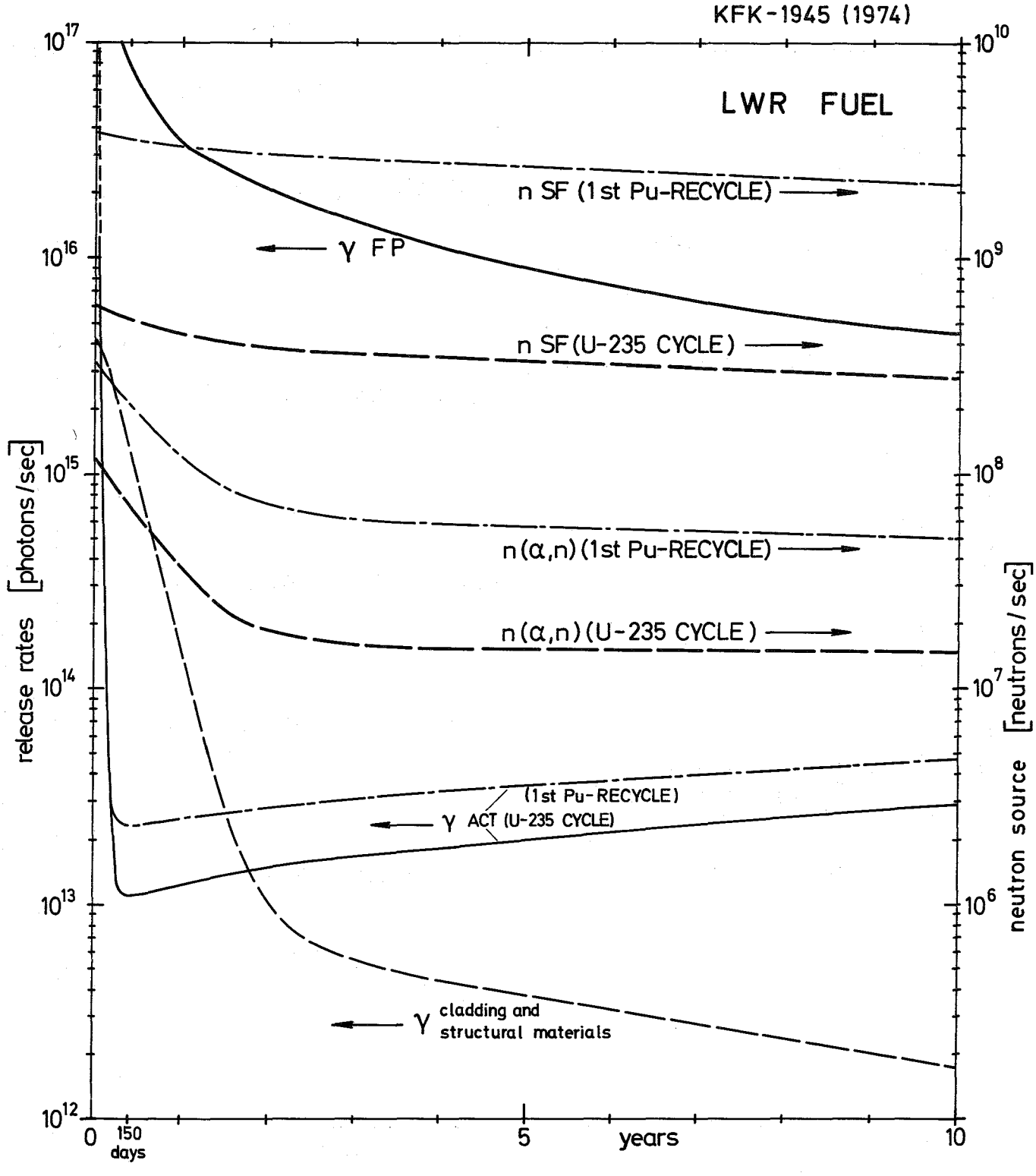

Fig.15 Photon and neutron release rates of spent LWR fuel (34000 MWd/t HM)

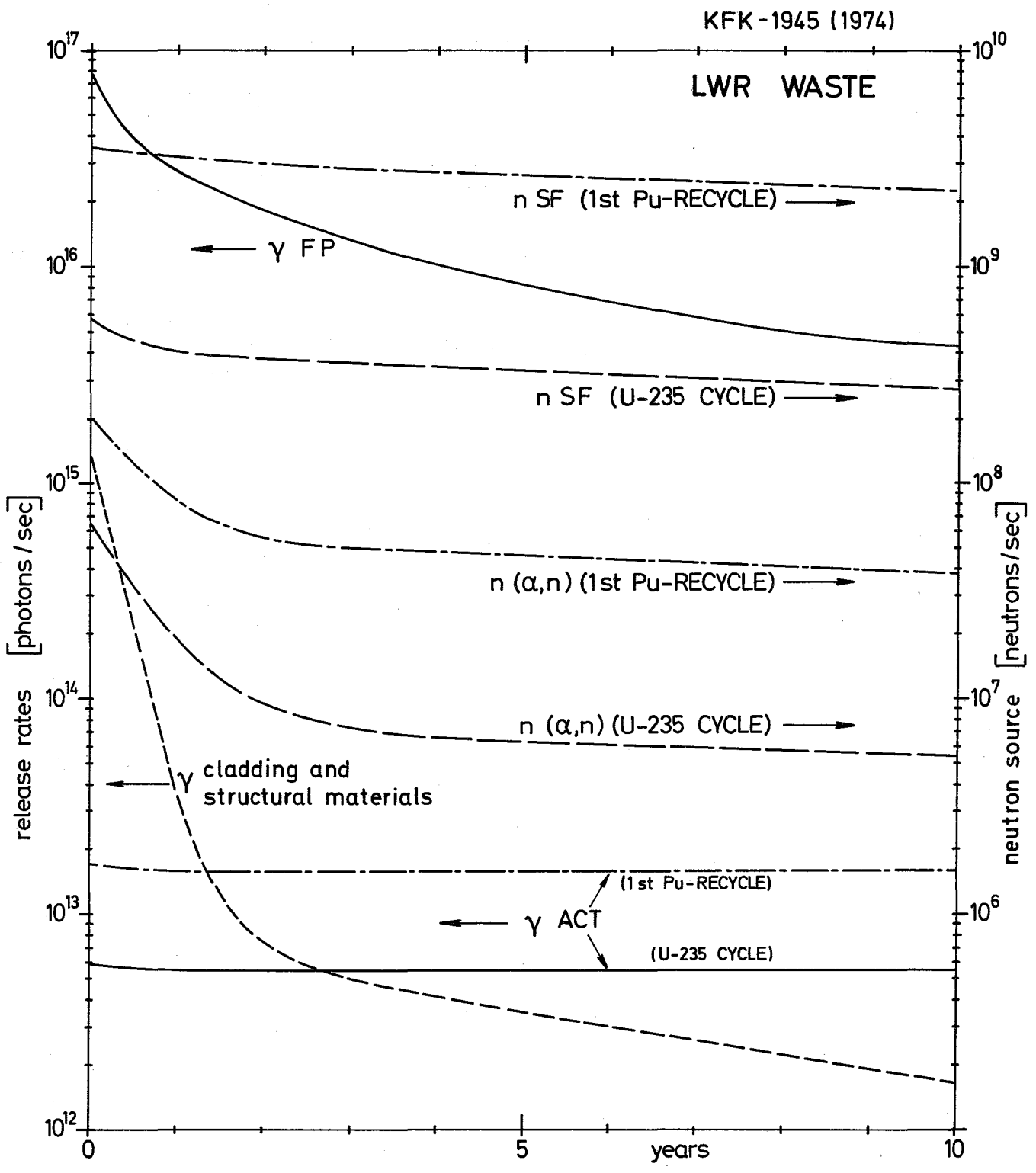

Fig. 16 Photon and neutron release rates of waste from spent LWR fuel reprocessed 150 days after reactor discharge (34000 MWd/t HM; 1% U and 1% Pu lost into HAW)